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GENERAL CONSIDERATIONS RELATED TO THE MEMBRANE MATERIAL LOCKING MODELS – A SHORT REWIEW

BY

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Abstract. The problem of clogging membrane pores has become an area of interest for the vast majority of researchers in the field, because according to the literature, membrane materials are very sensitive when it comes to clogging and blocking pores.

Therefore, this paper briefly describes the problems that occur during the process of obstruction the pores of the membrane. Models and characteristics of pore blocking mechanisms have also been developed.

It is essential to mention that the principal purpose of the paper, which which consisted to review the simulations and classical models that were optimized, used in the analysis processes of clogging of membrane materials, was successfully fulfilled.

According to those mentioned, the combined mathematical models of pore blocking (methods combined with three blocking mechanisms using Hagen-Poiseuille's law or standard 0-order blocking) have proven to be very effective in describing membrane clogging problems.

Keywords: membrane processes, blocking mechanisms, warping, mathematical models, impurities.

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1. Introduction

In the last period, unconventional wastewater treatment technologies have begun to be widely used in various fields of activity (industrial, domestic and commercial). Among these technologies, membrane systems are some of the most widely used, especially in the last period, unconventional wastewater treatment technologies have begun to be widely used in various fields of activity (industrial, domestic and commercial). Among these technologies, membrane systems are some of the most widely used (Li e*t al*., 2021).

The use of membrane technologies for the neutralization of effluents from various industrial activities has been and continues to be of interest to researchers, developing on the one part new materials membrane and on the other part improving existing and new models and simulations of membrane processes (Tien *et al.*, 2014; Mittal *et al*., 2021).

That being said, researchers have created and developed membrane materials and processes with particular characteristics, depending on the field of application of the technology (desalination of ocean waters, drinking water treatment, wastewater treatment from domestic and industrial activities, as well as in various applications of industrial processes). At their base on stay models and simulations that have a high degree of complexity, composed of laws and principles of mathematics and physics (Perfilov, 2018; Sanaei *et al*., 2017).

În another order of ideas, baromembranous processes are described as being of four types, namely Ultrafiltration, Reverse osmosis, Nanofiltration and Microfiltration. Depending on the application requirement, these processes can be used both in the hybrid system using both conventional and stand-alone processes in parallel (Liu *et al*., 1999; Kancherla *et al*., 2021).

In essence, the main role of this technology is to retain and neutralize the toxic compounds present in the mass of an effluent, taking into account several parameters, namely: pore size, morphology, particle size, material structure and all external factors of the process, thus obtaining an ultrapure water. However, membraning processes cause major problems in blocking the material due to the accumulation of cake on the surface of the membrane (Liu *et al*., 1999). This is also the reason why the vast majority of researchers have focused on this issue (Sanaei *et al*., 2017).

Depending on the composition of the effluent charges, the membrane materials are clogged either with organic matter, inorganic matter, solid particles in suspension, colloidal, or with microbial matter. Due to the fact that these impurities have smaller dimensions in relation to the pore diameter, some pass through the pore matrix and another part remain blocked in the pores of the membrane, thus favoring the formation of a solid or viscous layer on its surface (Liu *et al*., 1999).

To date, numerous studies and research have been conducted on the modeling and simulation of membrane clogging processes as well as membrane flow. Starting with the classic models of Darcy, Hermia, Bassirou, which mathematically describe the phenomena of membrane blockage and clogging, to complex models based on the development of new concepts and simulations that address at a more advanced and real level the problem of membrane clogging (Mahamadou Harouna *et al.*, 2019; Mondal *et al.*, 2020).

By using advanced and current mathematical simulators and models, efficient data can be obtained that helps to design and optimize the processes of clogging of membrane materials and not only (Kancherla *et al.*, 2021).

The goal of this paper is to focus on the brief description of classical and improved mathematical models and simulations used in the analysis of membrane clogging processes.

2. Baromembrane processes and operating parameters

According to the literature, membrane processes are classified taking into account the differences in operating pressure, internal pore diameter and molecular weight of particles, in four major processes MF, UF, NF and RO (Keir *et al.*, 2014).

These processes play an important role in defining the quality of the effluent, coming from various potentially polluting activities (Pharmaceutical industry, Food industry, Metallurgical industry, household commercial ones). All four existing processes have in common the same principle of operation and follow the same operating parameters (Hanspala *et al.*, 2009; Keir and Jegatheesan, 2014).

In other words, in a membrane system the effluent is transported with a certain pressure in the membrane module inside which semipermeable membrane materials are found. In fact, the membrane material is a selective barrier that ensures the retention of larger particles in relation to the pore diameter, thus obtaining two subflows, namely the high quality effluent called permeate and concentrated in the case of the product resulting from the retention (Hanspala *et al.*, 2009; Keir and Jegatheesan, 2014).

In terms of operating parameters, they are established and monitored throughout the membrane processes. According to the literature, pH, temperature, TMP, flow pressure, supply flow, are parameters that are found in most baromembrane mechanisms and at the same time are those that directly and indirectly influence the efficiency membrane material, costs and implicit the resulting effluent quality (Perfilov *et al.*, 2018; Kancherla *et al.*, 2021; Kim and Digiano, 2009).

The vast majority of researchers mentioned the importance and influence of parameters on the processes of clogging and soiling of membrane materials (Koonani and Amirinejad, 2019).

For example, in studies conducted by many researchers or observed that at a constant pressure the flow of permeate decreases in a unit of time, because of the formation of a cake on the area of the membranes (Kim and Digiano, 2009).

3. Presentation of membranes pore blocking processes

Blocking of the membrane is the result of the concentration of particles from of the feed effluent, in the infrastructure of the membrane cylindrical channels and implicitly on its area (Koonani and Amirinejad, 2019).

In other words, when the membrane material is affected by the phenomena of dirt, hydraulic diameter and porosity decreases and the thickness of the cake increases (Liu *et al*., 1999).

The proces of cake layer formation is showed in Fig. 1 where the accumulation of particles on the membrane can be seeing (Keir and Jegatheesan, 2014).

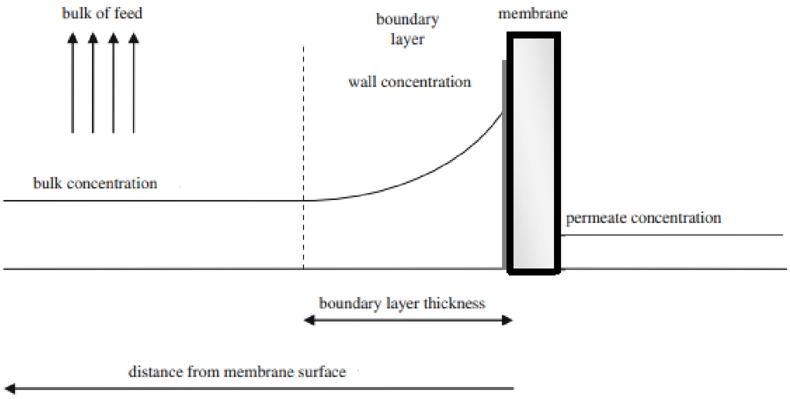

Fig. 1 – The phenomenon of cake formation (Keir and Jegatheesan, 2014).

At the creation of the cake on the surface of the membraning, an essential part is played by the nature of the effluent composition (solid, organic, inorganic particles, colloids, dissolved substances) that can be absorbed in the pore channels and by their accumulation the pores are blocked due to size reductions of the pores (Varsakelis and Papalexandris, 2020; Wang *et al*., 2021).

In general, membrane deposits are of two types, namely: - external deposition, where all the effluent content is accumulated on the membrane surface constitutes the so-called deposit layer, leads to slowdown of the filtration flow. - the standard deposition is owes to the adsorption of fine particles inside the pore structure, clogging its channel, the cause of the occurrence depends mainly on The geometry of the particles in relation to the pore measure (Lindamulla *et al*., 2021; Tien *et al*., 2014).

In the most common cases, the membrane materials are porous media with a very complex structure and morphology, within which are found many pores placed symmetrically or asymmetrically, interconnected eventually forming a matrix, this is also shown in Fig. 2, where they are represented images observed at microscope (Sanaei, 2017).

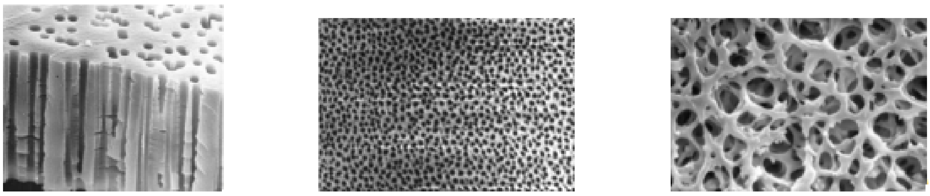

Fig. 2 – Microscopic representation of different membrane structures (Sanaei, 2017).

Due to the varied structure of the membrane, the particles are deposited differently, so the analysis of the peculiarities of membrane fouling is very complex. In the literature, there are simplistic and very extensive mathematical models. Therefore, researchers have developed models that successfully address the problems of membrane fouling, starting from the fundamental elements (Sanaei, 2017).

Starting from this idea, the existing blocking laws describe in a general framework the types and mechanism of dirt formation on the membrane material (Iritani and Katagiri, 2016).

These being said, in Fig. 3. The blocking mechanisms are represented which are of four types: Complete blocking, standard blocking, intermediate blocking and blocking by the formation of the particle start (Iritani and Katagiri, 2016).

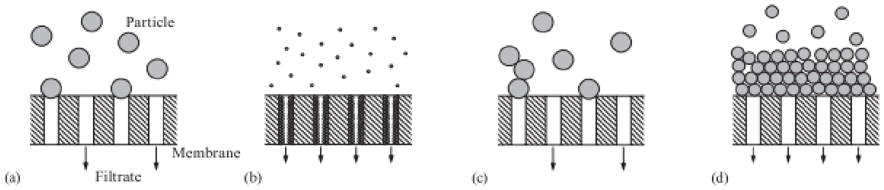

Fig. 3 – Representation of the four laws of pore blocking: (a) complete, (b) standard, (c) intermediate, (d) blocking by cake formation (Iritani and Katagiri, 2016).

Complete and intermediate blocking, as in Fig. 3, it is determined if the particle size is larger in relation to the pore diameter, and in the case of smaller pores, they are deposited by adsorption closing the pore channel, usually encountered at intermediate type blockages. In case of blockage by the constitution of the layer of agglomeration of impurities this is the result of the formation of complete and standard blockage (Iritani and Katagiri, 2016).

Mathematically, these blockages are described by a correlation, namely, the number of blocked channels per unit surface is directly proportional to the permeate volume of the membrane material. Therefore, the number of open pores during the filtration process is given by the following relation (Iritani and Katagiri, 2016):

$$N_0' - xv \tag{1}$$

Where: N_0' is the total number of open pores (m^{-2}), x is the number of particles that block pores per unit volume of filtrate (m^{-3}).

4. Standard methods for mathematical modeling of membrane dirt and membrane processes

In general terms, mathematical modeling is needed to describe, simulate, and optimize baromembrane processes. The further development of classical models led to the elucidation of complex pore blocking phenomena and at the same time proved to be very effective in making decisions on choosing the optimal membrane material and membrane cleaning and maintenance strategies (Sanaei, 2017; Jawad *et al*., 2021).

To date, researchers have developed models for analyzing the geometry, structure and morphology of pores, particular models have also been made taking into account the characteristics of effluent charges, parameters of entry and exit of membrane processes, and their interactions and influence on blocking problems and soiling of materials (Sanaei, 2017).

4.1. Modeling the process of membrane formation dirt

Fluxul Permeate flow is defined as the ratio of transmembrane pressure to the dynamics of permeate viscosity as well as the total strength of the membrane (Lindamulla *et al*., 2021).

This is exemplified in Eq. (2) as:

$$J = \frac{\Delta P}{\mu R_t} \tag{2}$$

Where: J - permeate flow, ΔP - TMP, μ - viscosity dynamics, R_t - strength of the membrane.

According to the classical equation of total series resistance, it comprises four elements described in relation (3):

$$R_t = R_m + R_i + R_r + R_p \tag{3}$$

Where: R_m - intrinsic resistance, R_i - irrecoverable resistance, R_r - reversible particle layer resistance, R_p - irreversible pore blocking resistance.

Analyzing each element separately, the following mathematical relations can be obtained:

1) For reversible resistance which is time dependent it may be expressed in Eq. (4) as:

$$R_r = \alpha m_r \tag{4}$$

Where: α - specific reversible resistance of membrane dirt, m_r - the amount of reversible impurities, this can be expressed as:

$$\frac{dm_r}{dt} = JX_T - k_r m_r \tag{5}$$

Where: K_r - the separation coefficient taking into account the transverse flow, and X_T is the concentration of impurities.

2) The determination of the irreversible resistance R_p on the pore blocking is given by:

$$R_p = k_p m_p \tag{6}$$

Where: m_p - the amount of reversible impurities that favor the blocking of pores, K_p - the resistance to dirt with different impurities that block the pores of the membrane, and m_p can be expressed as:

$$\frac{dm_p}{dt} = \beta J S_{SMP} \tag{7}$$

Where: β - impurity fraction and S_{SMP} the actual concentration of impurities.

3) The irrecoverable resistance is noted as R_i and is expressed a:

$$R_i = k_i m_i \tag{8}$$

Where: m_i - the amount of irreversible impurities, K_i - the concentration of impurities that favor irreversible dirt, and can be expressed to me as:

$$\frac{dm_i}{dt} = bJS_{SMP} \tag{9}$$

Where: b - the fraction of impurities causes irreversible soiling of the membrane.

4.2. The model of the effect of dirt on membrane flow

According to Hagen Poiseuille's equation, the effect of dirt on the membrane flux can be expressed according to Eq. (10) as:

$$J = \frac{\varepsilon d_p^2\, \Delta P}{32\delta\mu} \tag{10}$$

Where: J - the flux, ε - membrane porosity, d_p - pore diameter, ΔP - TMP, δ - membrane thickness and μ - fluid viscosity.

The Hagen-Poiseuille relation is a more updated form of Darcy's formula, where in the situation of relation (10) a laminar flow was represented inside the pores of the membrane (Liu *et al.*, 1999). Of course, Eq. (10) can be extended by introducing asymmetrically shaped pores instead of d_p - with DH - hydraulic diameter (11), which represents the relationship between the wet perimeter and the area of the flow section. This replacement is found in relation (11) as follows:

$$J = \frac{\varepsilon D_H^2\, \Delta P}{32\delta\mu} \tag{11}$$

Taking into account the viscosity of the liquid and the TMP, the membrane flux depends on the porosity of the membrane - ε, the effective thickness of the membrane - δ and the hydraulic diameter - DH (Liu *et al.*, 1999).

When a membrane is clogged, the hydraulic diameter and porosity decrease and the thickness of the material increases. Otherwise for a clean membrane, the flow, hydraulic diameter, porosity and thickness of the membrane is expressed as J_0, D_{H0}, ε_0, and δ_0, knowing these parameters the membrane flux can be expressed according to Eq. (12) as the ratio between flux clean membrane and membrane flux dirty.

$$\frac{J}{J_0} = \frac{(\varepsilon/\varepsilon 0)(D\_H/D\_H0)^2}{(\sigma/\sigma_0)} = (\frac{\varepsilon}{\varepsilon_0})(\frac{D_H}{D_{H0}})(\frac{\delta}{\delta_0})^{-1} \tag{12}$$

4.3. Concentration polarization model

This model aims to determine and simulate the efficiency of membrane modules in the retention of impurities by cross-flow (Li *et al.*, 2021). Taking into account the permeate flow J can be written according to the following relation (13):

$$C_S = \frac{C_b}{(1-S_0)\exp(-J/k_m)+S_0} \tag{13}$$

Where: C_s - solution concentration, C_b - volume concentration, K_m - is the mass transfer coefficient, S_0 - the selectivity coefficient of the solution.

4.4. Membrane pore clogging model

Since 1982, many researchers have made significant contributions to the modeling and simulation of pore clogging and blocking processes. The mechanisms and characteristics of membrane dirt formation are described and classified as four types: - standard, complete, intermediate blocking and deposits formation on the area of the membrane (Mahamadou Harouna *et al*., 2019; Iritani and Katagiri, 2016).

The principle of energy conservation for fluids flowing through the layer of particles deposited on the membrane material as well as in the membrane pores. It is characterized by kinetic energy given by the dynamic height and potential energy given by the hydraulic height, which is directly influenced by the pressure (Taghavijeloudar *et al*., 2019).

That being said, the principle of energy conservation is expressed in relation (14).

$$\frac{P}{\rho g} = \Delta H_{cake} + \Delta H_{membrane} \tag{14}$$

Where: P - operating pressure (Pa), ρ - effluent density (Kg / m^3), g - gravitational acceleration (m/s^2), H_{cake} - are the total energy losses due to the formation of the cake layer (m) and $H_{membrane}$ - membrane blockage (m).

The relation (14) shows that the principle of energy conservation is defined as the total applied pressure equal to the sum of all load losses (Taghavijeloudar *et al*., 2019).

The model of membrane dirt formation is represented in detail in Fig. 4, where both the schematic and graphical representation of the particle layer formation can be observed.

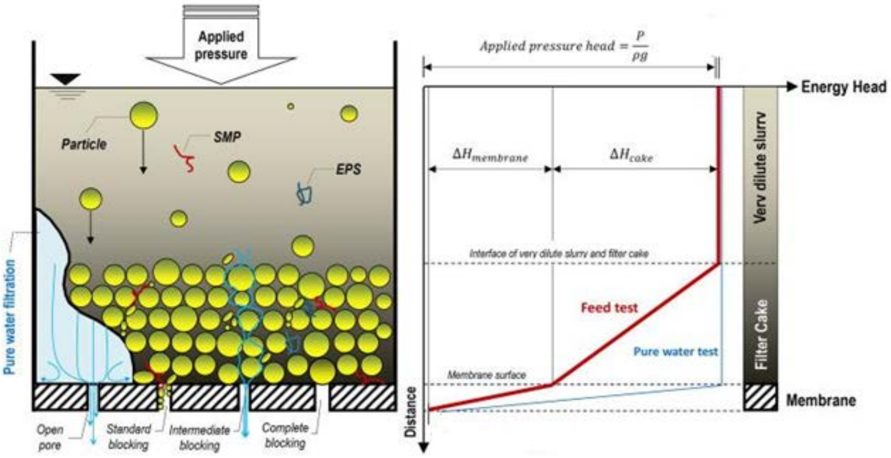

Fig. 4 – Representation of energy losses due to the formation of the cake layer and blockage of the pores by the four mechanisms during the membrane process (Taghavijelodar *et al*., 2019).

The principle of pore blocking and the classification of blocking mechanisms have been described and represented in detail in Chapter 3 of this paper.

Mathematical modeling of these locking mechanisms was performed for each of the following:

1) The standard blockage pattern is characterized by an accumulation of particles on the pore walls, thus obstructing the canal and therefore the quality of the permeate in this case is compromised (Taghavijeloudar *et al.*, 2019). The standard locking pattern is described mathematically in Eq. (15).

$$J = J_0(1 + K_s J_0 t/2)^{-2} \tag{15}$$

Where: K_s - standard closing constant (m^{-1}), J - solution flow (m/s), J_0 - initial flow (m/s), t - the time (s).

2) The complete blockage model in which the particles have a similar size to the pore diameter, which favors the complete blocking of the pores without their overlap and therefore

reduces the efficiency of membrane filtration (Taghavijeloudar *et al.*, 2019).

Mathematical modeling of this model can be found in Eq. (16).

$$J = J_0 e^{-k_b t} \tag{16}$$

Where: K_b - complete blocking constant (m^{-1}).

3) The intermediate blocking model assumes that a portion of the particles blocks some pores, while the rest accumulates on top of the particles already deposited (Taghavijeloudar *et al.*, 2019).

Mathematically this can be expressed according to Eq. (17).

$$J = J_0(1 + k_i J_0 t)^{-1} \tag{17}$$

Where: K_i - intermediate bocking constant (m^{-1}).

4) Cake layer formation pattern - accumulation and overlap of particles on the membrane surface.

This is expressed in Eq. (18).

$$J = J_0(1 + 2k_c J_0^2 t)^{-0.5} \tag{18}$$

Where: K_c - cake layer formation constant (m^2).

4.4.1. Combined models of pore blocking mechanisms

Following of research, new mathematical models have been developed that analyze and simulate the combined processes of membrane pore clogging (Khan *et al.*, 2020).

These being said in Fig. 5 are represented two combined locking mechanisms.

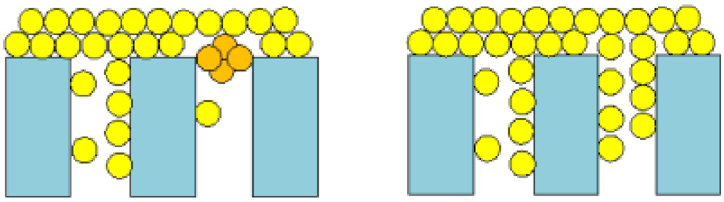

Fig. 5 – Combined models of membrane pore blockage.

The first figure shows the combined process of intermediate locking (SIC), and the second figure shows the formation of standard and complete locking (SCC) (Koonani and Amirinejad, 2019).

Based on these mechanisms, 5 new pore blocking models were later developed, consisting of three combined processes. The main goal in the development and creation of these models is the detailed analysis of the flow decrease behavior during membrane processes (Koonani and Amirinejad, 2019).

The first model consists in the mathematical description of the consecutive effects of the intermediate locking process, standard locking and locking by the formation of the cake. The second and third models was detalieded the consecutive effects of standard, intermediate locking, and cake formation on the membrane area, with the difference that the Hagen-Poisseuille formuls were used for the filtered flow. In the case of the latest blocking mechanisms models, the standard blocking process was optimized by using the zero order time-dependent equation for the deposition of solids in the channel of the membrane pores (Koonani and Amirinejad, 2019).

The mechanisms mentioned above are described mathematically according to Table 1 (Koonani and Amirinejad, 2019).

Table 1

Mathematical models combined with three mechanisms

Nr. Crt.	Mathematical Model	Application parameters	Mathematical relationship
1	Standard Blocking And Intermediate Pore And Cake Formation (Particle Layer)	α', f', R', R_{c0}, β	$\frac{Q}{Q_0}=\frac{1}{(1+\beta Q_0 C_b t)^2}\left(1-\frac{\alpha'}{\beta A_0(1+\beta Q_0 C_b t)}+\frac{1}{\beta A_0}\right)^{-1}+$ $\int_0^t \frac{\alpha' Q_0 C_b \beta^2 A_0((1+\beta A_0)(1+\beta Q_0 C_b t_e)-\alpha')^{-2} dt_e}{\sqrt{[\frac{R_{c0}}{R_m}+(1+\beta Q_0 C_b t_e)^2]^2}+2\frac{f' R' \Delta P C_B}{\mu {R_m}^2}(t-t_e)} dt_e$
2	Standard Blocking And Intermediate Pore And Cake Formation (Using Hagen - Poiseuille Law)	α', f', R', R_{c0}, α_{in}	$\frac{Q}{Q_0}=\left(1+\frac{2J_0 C_0 \alpha_{in}}{\delta_m}t\right)^{-1}\left(1+\frac{\alpha'\delta_m}{2\alpha_{in}}\ln\left(1+\frac{2J_0 C_0 \alpha_{in}}{\delta_m}t\right)\right)^{-1}+$ $\int_0^t \frac{\alpha' J_0 C_b \left(1+\frac{2J_0 C_b \alpha_{in}}{\delta_m}t_e\right)^{-1}(1+\frac{\alpha'\delta_m}{2\alpha_{in}} ln\,(1+\frac{2J_0 C_b \alpha_{in}}{\delta_m}t_e))^{-2}}{\sqrt{[\frac{R_{C0}}{R_m}+(1+\frac{2J_0 C_b \alpha_{in}}{\delta_m}t_e)]^2}+2\frac{f' R' \Delta P C_b}{\mu {R_m}^2}(t-t_e)} dt_e$

3	Standard Blocking, Complete Pore Blocking And Cake Forming (Using Hagen - Poiseuille Law)	α, f', R', R_{c0}, α_{in}	$\frac{Q}{Q_0} = \left(1 + \frac{2J_0C_b\alpha_{in}}{\delta_m}t\right)^{-1\left(\frac{\alpha\delta_m}{2\alpha_{in}}\right)}$ $+\int_0^t \frac{J_0\alpha C_b(1+\frac{2J_0C_b\alpha_{in}}{\delta_m})^{-(1+\frac{\alpha\delta_m}{2\alpha_{in}})}}{\sqrt{[\frac{R_{e0}}{R_m}+(1+\frac{2J_0C_b\alpha_{in}}{\delta_m}t_e)]^2+2\frac{f'R'\Delta PC_b}{\mu {R_m}^2}(t-t_e)}}dt_e$
4	Standard Zero-Order Blockage And Intermediate Pore Blockage Like Cake Formation	α', f', R', R_{c0}, K_{s0}"	$\frac{Q}{Q_0} = (1-K''_{s0}t)^4(1-\frac{\alpha' C_bJ_0}{5K''_{s0}}((1-K''_{s0}t)^S-1)))^{-1}+$ $\int_0^t \frac{\alpha' C_bJ_0\left(1-K''_{s0}t_e\right)^4(1-\frac{\alpha' C_bJ_0}{sK''_{s0}}\left(\left(1-K''_{s0}t_e\right)^S-1\right)))^{-2}}{\sqrt{[\frac{R_{c0}}{R_m}+(1-K''_{s0}t_e)^{-4}]^2+2\frac{f'R'\Delta PC_b}{\mu {R_m}^2}(t-t_e)}}dt_e$
5	Standard Zero-Order Blockage And Complete Pore Blockage, Cake Formation	α, f', R', R_{c0}, K_{s0}"	$\frac{Q}{Q_0} = (1-K''_{s0}t)^4\exp\left(\frac{\alpha C_bJ_0}{5K''_{s0}}((1-K''_{s0}t)^S-1)\right)+$ $\int_0^t \frac{\alpha C_bJ_0(1-K''_{s0}t_e)^4\exp(\frac{\alpha' C_bJ_0}{sK''_{s0}}\left(\left(1-K''_{s0}t_e\right)^S-1\right))}{\sqrt{[\frac{R_{c0}}{R_m}+(1-K''_{s0}t_e)^{-4}]^2+2\frac{f'R'\Delta PC_b}{\mu {R_m}^2}(t-t_e)}}dt_e$

The combined models mentioned in Table 1 have been applied by many researchers. Specifically, a study was done in which the new models were applied precisely because the classic models do not efficient predict problems related to membrane blockage. That being said, different concentrations of BSA (Bovine serum albumin) were used to monitor the blocking processes at certain parameters (Koonani and Amirinejad, 2019).

BSA concentrations in the effluent feed were monitored and determined at time Q0 - which represents the initial volume flow of the clean membrane ($m^3 s^{-1}$). Specifically, four BSA solutions were used, with concentrations ranging from 1-8 g/L. Appropriate, to the first model, reported in Table 1, the combined successive effects of the three mechanisms (standard, intermediate and cake smoking) were determined, the results of which are shown in the graph in Fig. 6 (Koonani and Amirinejad, 2019).

As can be seen in the graph in Fig. 6, the flow decreases sharply as evidenced by the pore-blocking mechanisms and subsequently a slight decrease is observed during filtration when the cake start begins to form. In the case of flow rate for lower concentrations of BSA (1-2 g/L) are constant, this is explained by the fact that blocking takes place through a combination of locking mechanisms. Otherwise, the flow at concentrations higher than 8 g/L decreased faster as proof of blockages of pore from the beginning of the experiment and cake formation throughout the filtration period (Koonani and Amirinejad, 2019).

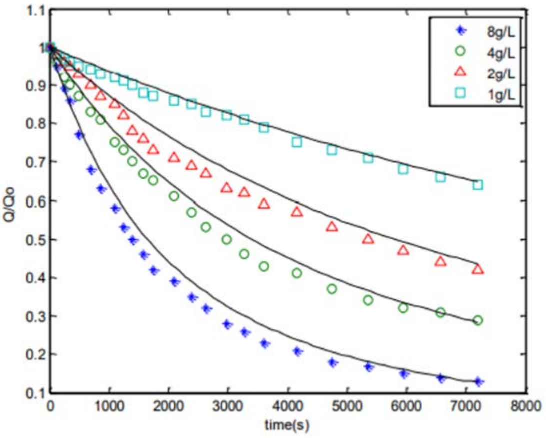

Fig. 6 – Experimental data obtained from the determination of the normalized flow for filtering BSA solutions (20°C and 14 kPa) using model 1 described in Table 1 (Koonani and Amirinejad, 2019).

The graph in Fig. 7 shows the experiments for the second model.

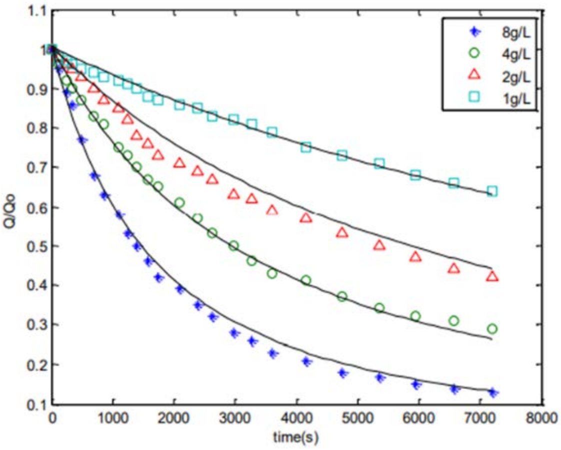

Fig. 7 - Experimental data obtained from the determination of the normalized flow for filtering BSA solutions (20°C and 14 kPa) using model 2 described in Table 1 (Koonani and Amirinejad, 2019).

The triple mechanism applied to filter the BSA solution using Hagen-Poiseuille equations. It can be seen that the flux does not change substantial depending on the time and the concentration of the diluted. Changing the flux curve over time, show the transition stage between blockage and membrane dirt formation (Hamed Koonani *et al*., 2019).

The graph in Fig. 8 shows the experiments for the third model.

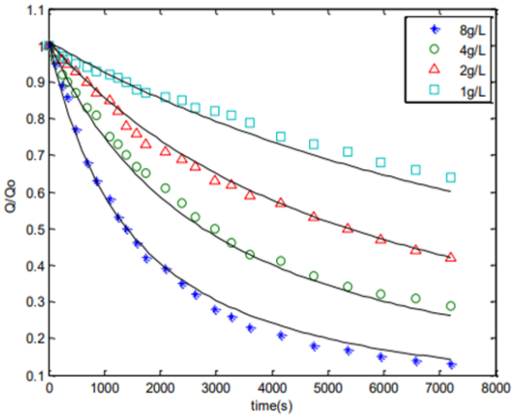

Fig. 8 – Experimental data obtained from the determination of the normalized flow for filtering BSA solutions (20°C and 14 kPa) using model 3 described in Table 1 (Koonani and Amirinejad, 2019).

This case is similar to model 2, except that it describes complete pore blockage. It can be seen how the standard and intermediate blockage appear at the beginning of the soiling process, while the standard blockage disappears during the filtration process, due to the complete blockage of the pores (Koonani and Amirinejad, 2019).

The graphs in Figures 9 and 10 show the experiments for the fourth and fifth models.

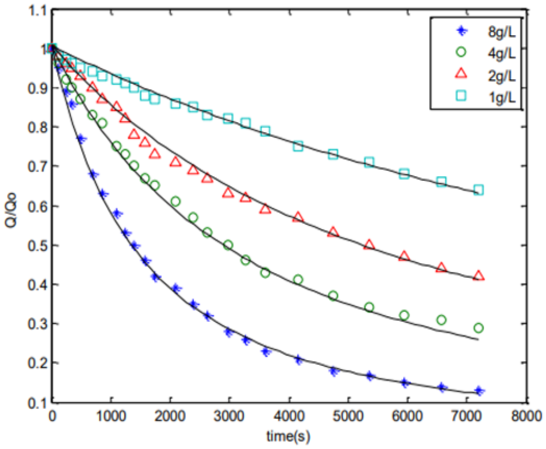

Fig. 9 – Experimental data obtained from the analyze of the normalized flow for filtering BSA (20°C and 14 kPa) using model 4 described in Table 1 (Koonani and Amirinejad, 2019).

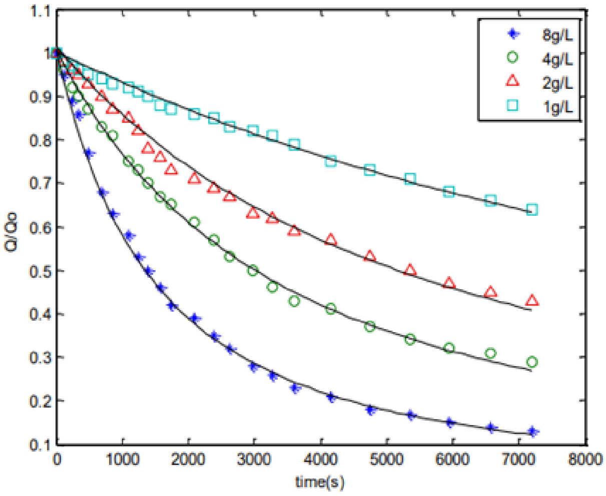

Fig. 10 – Experimental data assimilated from the analyze of thenormalized flow for filtering BSA solutions (20°C and 14 kPa) using model 5 described in Table 1 (Koonani and Amirinejad, 2019).

According to the two graphical representations in Figs. 9 and 10, the three models were determined using the 0th order equation. For a more accurate result, the equations were determined at 10-10 (Koonani and Amirinejad, 2019).

Therefore, the study concludes that compared to the first three models, the zero-order model has been shown to be very effective in modeling and simulating pore-blocking processes (Koonani and Amirinejad, 2019).

5. Conclusions

As a result, the efficiency of membrane technologies in retaining all impurities in the body of wastewater, they are used in many fields.

With the development of technology, new membrane materials have emerged designed to neutralize pollutant compounds in wastewater. However, membrane materials have major problems in clogging and soiling, both during and after operation.

That being said, many studies have made their mark and at the same time have given special importance in the description and development of models and simulations of the processes of clogging of membrane materials as well as on the membrane flow.

Thus, in this paper, mathematical models were briefly described regarding the flow of permeate and membrane, as well as the problems of clogging and blocking of pores. The main problem that leads to clogging of a membrane material and implicitly to the inefficiency of the process, is the appearance of blocking mechanisms, described in detail in this paper.

Starting from the classical models, which are limited in the description of the pore blocking processes, numerous mathematical models were later developed by researchers through which the efficiency and filtration rate of the membrane material can be analyzed at a much better level. Overall, all the mathematical models used to describe the problems that arise in the exploitation of the membrane are either combined or developed, starting from the basic mathematical models.

Combined pore blocking models have been further developed in this paper, including combined methods with three blocking mechanisms using Hagen-Poiseuille's law or standard 0-order blocking, which later proved to be the more efficient.

Regarding future research in this niche, special attention can be paid to the development of simplified mathematical models for the processes of soiling and cleaning of membrane materials.

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CONSIDERENTE GENERALE CU PRIVIRE LA MODELELE DE BLOCARE EXISTENTE ȘI DEZVOLTATE ALE MATERIALELOR MEMBRANARE

(Rezumat)

Problema colmatării porilor membranei a devenit domeniul de interes pentru marea majoritate a cercetătorilor în domeniu, deoarece conform literaturii de specialitate, materialele membranare sunt foarte sensibile atunci când vine vorba de obturarea și blocarea porilor.

Prin urmare, în prezenta lucrare au fost descrise sumar problemele care survin în timpul procesului membranar și implicit influența parametrilor de funcționare asupra colmatării porilor membranei. De asemenea, au fost detaliate caracteristicile și modelele matematice ale mecanismelor de blocare a membranei.

Este important de menționat faptul că scopul principal al lucrării, care a constat în descrierea modelelor și simulărilor matematice clasice și optimizate utilizate în analiza proceselor de colmatare a materialelor membranare, a fost îndeplinit cu succes.

Conform celor menționate, modelele matematice combinate de blocare a porilor (metode combinate cu trei mecanisme de blocare folosind legea lui Hagen–Poiseuille sau blocarea standard de ordin 0) s-a dovedit a fi foarte eficiente în descrierea problemelor de colmatare a membranelor.