Hydrodynamic Surface Evaluation of a Polymeric Reverse Osmosis Membrane Using a Crossflow Cell

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The purpose of this research was to visualize the fouling process of a flat-sheet polymeric membrane into a flow cell, using particles to study their deposition onto the membrane surface. This set of experiments was analyzed from an imagistic point of view, designing for this purpose a measuring installation where hydrodynamic surface evaluation was carried out with an image processing concerning to the reverse osmosis operation. To ensure the measurements accuracy, calculations, logical approximation, and comparisons were made with existing and verified models, revealing that the differences were insignificant.

Keywords: filtration, fouling membrane, reverse osmosis, imaging analysis

Natural waters, irrespective of their origin, contain many impurities, of a mineral and organic nature, dissolved (salts, gases) or dispersed (suspended matter), in a higher or lower concentration, which they train during natural circulation [1].

Wastewater treatment and purification is a set of measures and processes by which the mineral, organic and bacteriological impurities contained in the waste water are eliminated or reduced to certain limits, such that these waters do not affect the qualitative characteristics of the receptor in which they are evacuated. For treatment and wastewater treatment several processes based on physical, chemical and biological processes are used [1-7].

Filtration is a method of separating solid impurities from fluids, following flow through permeable porous media, called filter media or filters [8-13].

The quality of the underground water and groundwater is increasingly subject to the harmful influence of anthropogenic substances, agricultural pollution and the increasing presence of chlorinated hydrocarbons. Optimal solutions that combine conventional processes with advanced technologies, such as membrane filtration, guarantee a high level of flexibility and superior water quality [8-17].

The processes that involve the use of membranes, including RO, are widely used in water treatment processes and are of importance growing globally. As a result, membrane filtration potability plants, allow for better, more complete and easier monitoring of water sources [18, 19].

The main factors influencing the performance of a system based on reverse osmosis are [19-21]: pressure, temperature, concentration of dissolved salts in the inlet water. Reverse osmosis is one of the most effective methods of water treatment for dangerous contaminants such as nitrates, nitrates, mercury, arsenic, lead, pesticides, fluorides, etc. [19-25]. Reverse osmosis systems retain dissolved chemicals as well as biological agents in water, resulting water having a high degree of purity [22, 25]. The membranes fouling is the most important problem in the water filtration process, for which continuous studies are being done to reduce this effect, limiting the effectiveness of membranes can affect negatively plant performance [25, 26].

Visualization of the fouling process of the membranes was done by hydrodynamic evaluation of the surface of an RO polymeric membrane with a flat-sheet configuration using various kinds of particles, to view the filtering process in the flow cell through an imaging analysis.

The evaluation of hydrodynamics, the surface of the polymeric membrane, using different types of pollutants, can provide useful information in the art and responses in terms of velocities or flow behavior in cells via the membrane.

The present study aims to investigate de possibility to establish some correlations between polymeric reverse osmosis membrane operation and a crossflow cell hydrodynamic surface evaluation.

Experimental part

The flow cell is a cross flow filtration unit (cross-flow of water) for the laboratory, specially designed to evaluate flat membrane models in a variety of applications [27]. The flow cell used to perform flat membrane experiments is a unique model made of Plexiglas's (approximately 92% transparent), with both smooth and glossy faces, with extreme resistance to impact and natural protection against ultraviolet radiation [27].

The flow cell simulates the flow dynamics on commercially available membrane elements, such as the industrial spiral. By using a combination of Plexiglas, lamellas, feed spacing and membrane, the operating conditions and fluid dynamics can vary for wide ranges [27].

In figure 1, the technological scheme of the plant containing the flow cell is represented.

Experimental research implied the use of particles to visualize the flow of water in the flow cell or visualization

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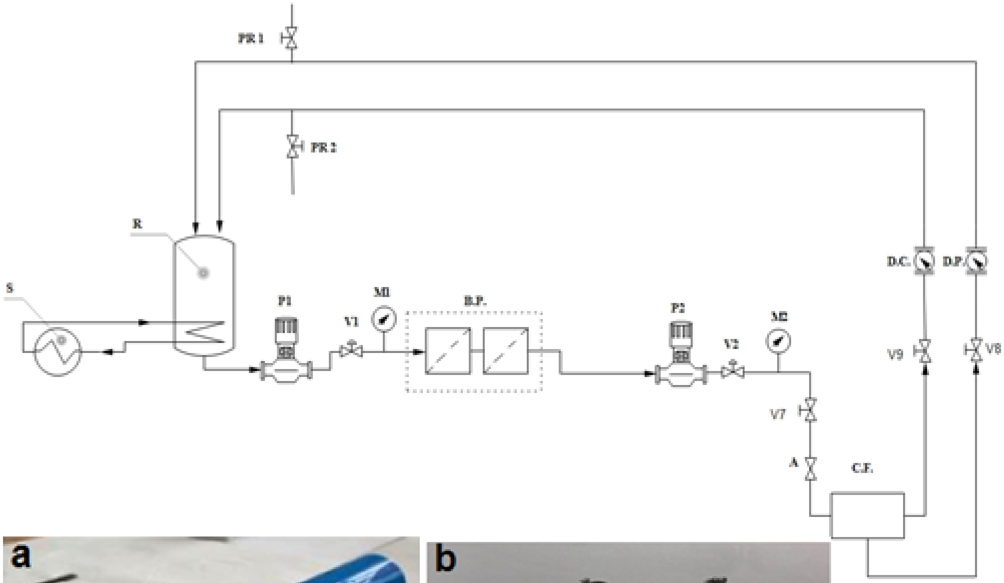

Fig. 1. Technological scheme of the installation comprising the flow cell [27]: R -tank with water-reactive mix (50L capacity); S -water temperature maintenance system (heat exchanger); M1, M2 - manometer; B.P. -pre-filtration battery; V1, V2 -taps; P -pressure pump; A -valve for introducing the fluorescent solution; C.F. -Flow cell; D.P. -flowmeter for permeate; D.C. -flowmeter for concentrate; PR1 -tap for collecting the permeate sample; PR2 - tap for collecting the concentrate sample

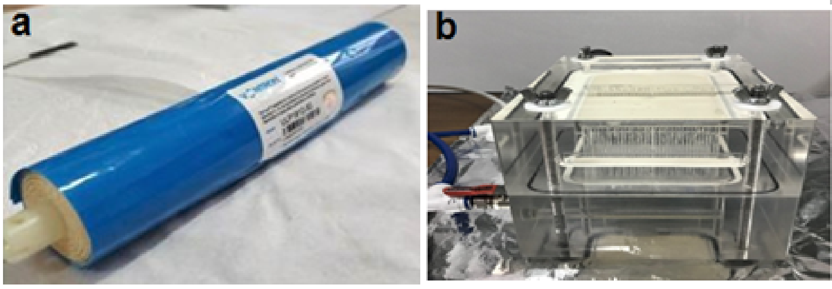

Fig. 2. Polymeric membrane of RO, ULP type 1812-50 [27]: a) Image of RO membrane used for flux cell experiences; b) Flow cell equipped with RO membranes - images from the preparation of the experiments

of the fouling over time of the membrane. For this, a closed frame was built for optimal viewing, using the cold light of a lamp. Also, recordings during the operation of the installation were made using a Nikon camcorder D5200 [27].

The flat membranes used in these researches have a flat configuration and are mainly rectangular. The membrane used in the present research is a polymeric membrane of RO (reverse osmosis), ULP model 1812-50 (VONTRON) (fig. 2a). From this membrane were performed analysis models for flow cell experiments (Fig. 2b) [27].

Designing experiments

These experiments refer to the use of imaging analysis in order to highlight the fouling process of the filter membrane. This group of experiments was organized following a bifactorial form equation [27]:

$$A3_3 \times B3_3 , \qquad (1)$$

where: A3 is the input pressure factor (2.5, 4.0 and 6.0 bar); B3 - factor representing the amount of nanoparticles (5, 10 and 25 g).

Methodology for fouling membrane analysis

In order to analyze the fouling process of the membrane during the filtering process, a visual analysis of this process was chosen. For this purpose, a flow cell, especially made of Plexiglas's, was used in order to monitor the manner of deposition of solid suspensions on the surface of the filter membrane. Because this method was chosen, the flow cell, the film chamber, the light source, was placed in an aluminum foil lined enclosure to achieve the following conditions [27]:

- Eliminating external light intensity variations that may influence experimental results;
- Create a uniform dispersion of light generated by the light source within the enclosure;
- In order to highlight the manner of deposition of solid particles on the filtering surface, solid particles with dimensions ranging from 44.6 - 115.5μm were chosen.

Measurements were performed using an MTM-1A metallographic electronic microscope, the average color-associated value of which is 155.9 (figs. 3a and 3b). This value was obtained using the GIMP program.

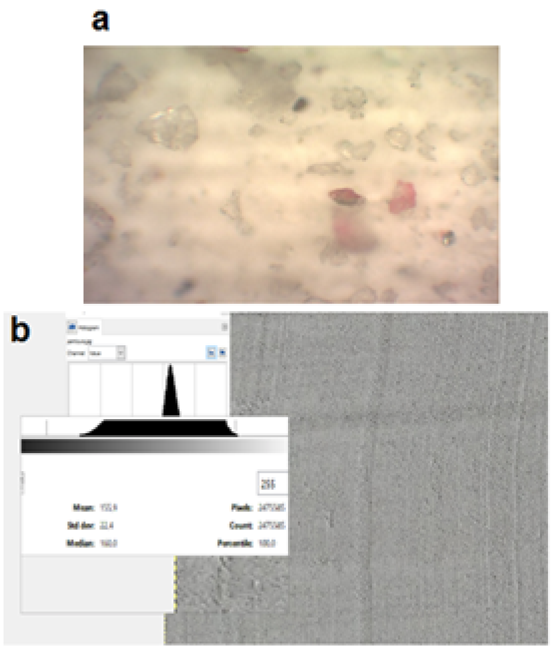

Fig. 3. a) Solid particles identified by metallographic electronic microscope;b) The average value associated with the color spectrum [27]

As a result of the films, they were processed taking into account the working methodology. This method only highlights the deposition of nanoparticles on the surface of the membrane over time, not their quantity.

The working methodology, designed specifically for this batch of experiences, comprises the following steps [27]:

-Because video analysis of the filtration process is not possible, it was chosen to analyze certain frames. These were chosen so that there is the same amount of time between the frames, respectively the frames were taken at a time interval of 1 min. This process was accomplished with Virtual Dub program;

-The photos thus obtained were imported into the Mathcad program where they were analyzed. The image processing steps are described below:

The images were inserted into the program using the READ_IMAGINE read function;

The histogram of the image was created using the following steps (Mathcad work code):

H: = inhist (A, 256)

k: = 0 … rows (H)-1

k_range_k: = k

HK_k: = H_k

where: A represents the analyzed file or image; H - the new file conversion using the inhist function that creates the histogram, using all the color spectrum, respectively 256 (fig. 4b); k - represents a new function to transform files A and H into matrix files; HK - The final form of the file under analysis. For example, choose the solid particle mass file to be used within this experiment batch (fig. 4).

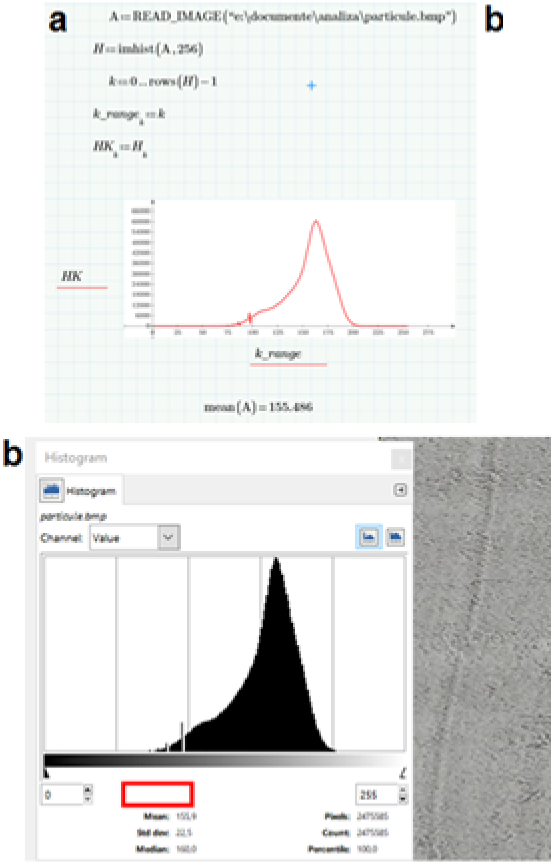

Fig. 4. Representing the histogram [15]:
a) by the Mathcad program; b) by the GIMP program

The analysis of the images in figure 4 shows that there is no difference between the two methods and the average value, which in the GIMP program is 155.9 (marked red) can be determined in the Mathcad program with the help of the function mean. So, all images processing of membrane fouling can be accomplished using MathCAD and the mean function without any errors [27].

Results and discussions

In order to analyze the membrane fouling process during the filtration process, a visual analysis of this process was chosen. For this purpose, the methodology presented above was used. The flow cell system in which a cut-out membrane was mounted from the commercial reverse osmosis polymeric membrane, ULP type 1812-50.

After analyzing the films and frames corresponding to each minute, a series of graphical representations were made, which aimed at highlighting the color spectrum, respectively the fouling of the filter material by deposition of solid colored particles on the filtering surface [27].

For the beginning, a set of images was taken at 5-minute intervals in order to achieve for them the histogram representation, which was performed for a feed pressure of 2.5 bar and for a quantity of solid particles of 5 g. From the analysis of the histograms thus obtained (fig. 5) it is observed that there are differences between the graph alloy but also between the values included in these types of graphic representations [27].

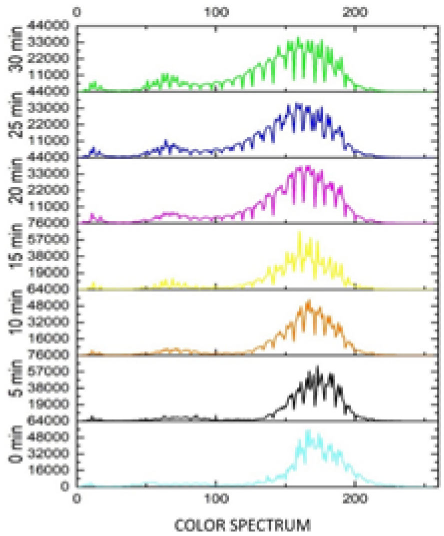

Fig. 5. Variation of color spectrum (uc) for different time intervals [27]

Taking into account the working methodology presented above, the results obtained, respectively the variations in time of the average values of the color spectrum, are presented as follows [27]:

- for a pressure of 2.5 bar - figure 6:

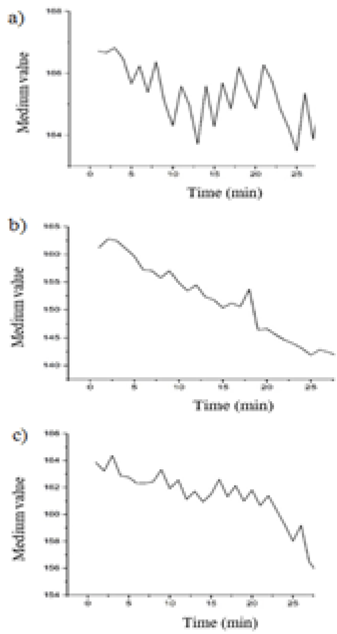

Fig. 6. Time variations of mean color spectrum values corresponding to a feed pressure of 2.5 bar: a) for the quantity of solid particles of 5 g; (b) for the quantity of solid particles of 10 g; c) for the amount of solid particles of 25 g [27].

- for a pressure of 4 bar - figure 7:

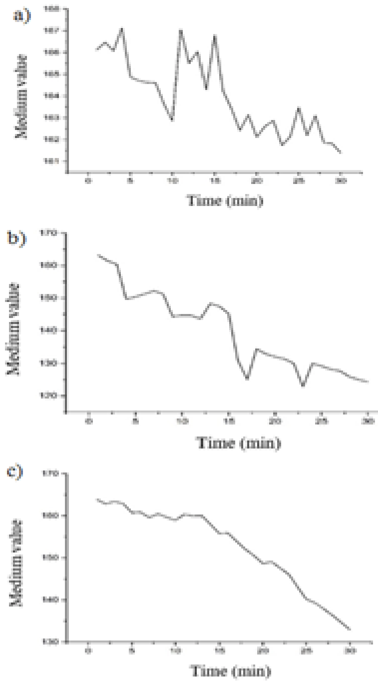

Fig. 7. Time variations of the average color spectrum values corresponding to a 4 bar feed pressure: a) for the 5 g solids quantity; (b) for the quantity of solid particles of 10 g; c) for the amount of solid particles of 25 g [27]

- for a pressure of 6 bar - figure 8:

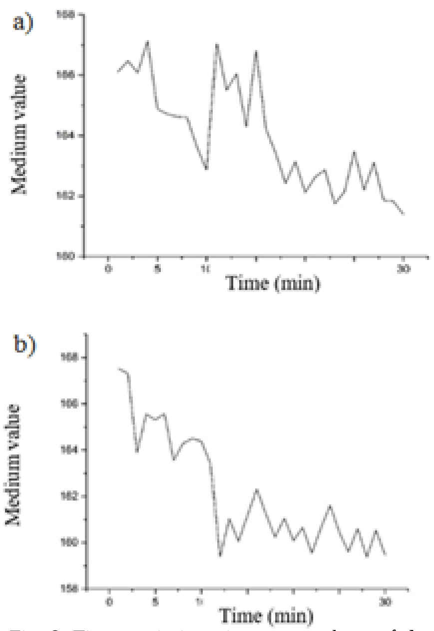

Fig. 8. Time variations in mean values of the color spectrum corresponding to a supply pressure of 6 bar: a) for the quantity of solid particles of 5 g; b) for the amount of solid particles of 10 g [27].

As a result of the analysis of the graphical representations in the figures presented above, we find that [27]. This method of viewing the fouling process through imaging analysis can be used but is influenced by a number of factors:

- the variation in luminous intensity, which plays an important role and these results in variations in the mean values of the color spectrum, the parameter that is studied in this case. This is shown in figure 6.b and figure 7.b and c where the average color spectrum is less than the average particle color spectrum used, i.e. 155.9 uc;

- the experiments were carried out for a period of 30 min, which proved to be insufficient to carry out the total fouling process;

- the method of obtaining data necessary to highlight the fouling process used a technical software, Mathcad, in which more images could be analyzed consecutively and the histogram and variation of the mean value of the color spectrum over time could be made;

- regardless of the operating parameters of the equipment used or the quantity of material used, it is found that the average value of the color spectrum has a decreasing trend over time, indicating that the solid particles are deposited on the filtering surface, leading to its fouling.

Conclusions

Based on the results obtained in the imaging analysis of the membrane fouling process, it can be concluded that the use of this method can not determine the quantity of a component, but it may indicate its existence [27].

At the same time, the fouling process was highlighted by color spectrum values in color units (0 uc - for black color and 255 uc - for white color) [27].

Also, the important advantages of this method are:

-highlighting the variation of a parameter in our case of the mean spectral value over time;

-determination of the average spectral value with accessible equipment, such as a camera, a well-lit enclosure and a computer with an imaging program;

-use in industrial processes to control fouling of filter membranes.

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