Journal of Nanotechnology and Materials Science
OMMEGA Publishers
ISSN:2377-1372
OPEN ACCESS
Review Article
DOI: 10.15436/2377-1372.19.2491

Design of a Cross Flow Filtration Module Intended to Minimize Fouling and Concentration Polarization

Landry Omalanga[1, 2*], Precious Biyela[1,2], Edward Pretorius[1]

[1]D1Department of Civil Engineering and the Build Environment, University of the Witwatersrand.
[2]National Research foundation, NRF Thuthuka

***Corresponding author:** Landry Omalanga, Department of Civil Engineering and the Build Environment, University of the Witwatersrand; E-mail: landromal@gmail.com

Abstract

Cross flow flitration module is mainly used for membrane separation process (MSP) which is more driven by pressure force, feed concentration and permeability. However, It has been shown that most filtration modules designed at laboratory scale face serious issues of pressure drop,membrane fouling and concentration polarization. These disavantages might be the result of an inadequate configuration of the designed filtration module itself or due to the technique that is used to send the feed inside the filtration module. This paper describes the design of a cross flow filtration module intended to minimize the pressure drop and other membrane problems as fouling and concentration polarization that can occur inside the filtration module during water or waste water treatment process. Navier- Stokes equation and principles are applied in order to improve and optimize the geometry of the fluid cell inside the filtration module while the principle of stress-strain was also respected in oder to optimize the mechanical performance of the filtration module. Water treatment performance was evaluated with experimental results obtained after the filtration process.

Keywords: Cross flow filtration module; Membrane separation Process; Pressure drop; Fouling, Concentration polarization.

Introduction

Cross flow filtration module at laboratory scale is commonly used to assess the membrane separation performance. This type of filtration module can be scaled up at industrial scale filtration modules of much greater area. In membrane separation process, a certain range of pressures is used in order to send the feed in the module that contains a permeable membrane placed inside the membrane cell (membrane chamber) (Figure 1). It should be noted that there is usually a difference of pressure that occurs between the feed side of the filtration module and the permeation flows through the membrane (permeate).

A membrane is barrier which allows the transport of the same kind or sized molecules (permeate) and stops the passage of others (retentate) (Figure 1). The membrane definition is quite similar to a normal filter; however, by convention the term filter is used for filtration process involving a particular range of suspensions containing particles larger than 1-10 µm[1]. The transport of the molecules is driven using driving forces such as: temperature, pressure, concentration, etc. The membranes can be natural or synthetic by their origin[2]. A traditional experimental set-up for membrane separation process is described in Figure 2. Note the pressure and vaccum pump should be connected to the filtration module in order to send the feed inside the membrane pores. Figure 1

Received date: April 29, 2019
Accepted date: May 9, 2019
Published date: May 12, 2019

Citation: Landry Omalanga, et al. Design of a Cross Flow Filtration Module Intended to Minimize Fouling and Concentration Polarization. (2019) J Nanotechnol Material Sci 6(1): 30

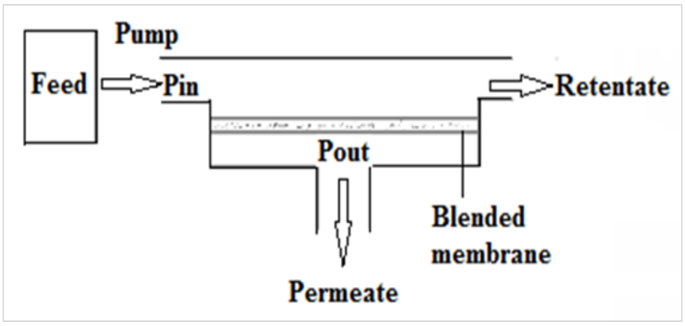

Figure 1: Cross flow filtration module design

During filtration process that uses pressure to feed the solution into the system, the important operating conditions to membrane separation performance are feed concentration (physical and chemical properties), temperaturature, pressure, velocity[1]. The process can be maintained at room temperature (25°C) by using a thermostat. The Feed solution should be characterize prior every filtration process, the permeate (pure water flux) should be collected for characterization while the retentate can be recycled back to the feed tank. Feed flow and pressure can be determined by using a pressure – vaccum pump. Pressure can be used as the main parameter that help to assess the permeate flow. The cross flow velocity (feed flow) on the membrane surface can be used to enhance concentration polarization, which is an increase on solute concentration on the membrane surface while fouling can be defined as the accumulation of substances on top of the membarne surface or inside the membrane pores[2]. Concentration polarization can be responsable of membrane fouling and it can impact negatively the membrane separation performance[2]. Therefore, it is also very important to ensure that there is uniform hydrodynamic conditions on the membrane surface. High pressure drop has been observed in several designed filtration modules due to lack of uniform feed flow and because of the presence of fouling or concentration polarization that corrupt the pressure value on the membrane surface[3].

In this experiments, a special pressure-vaccum pump was connected to the cross flow filtration module in oder to use differents pressure forces while sending the feed into the system in order to test the cross flow filtration module. The feed was sent tangentially into the system in order to reduce membrane fouling, since the water solution that flows tangentially can actually play the role of washing the surface of the membrane that is placed in particular cell of the module[4]. The cross flow filtration module is different from the dead end filtration module where the feed is sent horizontally into the system and it becomes very hard to avoid fouling and concentration polarization while using the dead end system[5].

Firstly, this paper explains how the fluid dynamic study of the module was used to design a proper cross flow filtration module that reduces fouling and pressure drop issues. Secondly, the paper also discusses about the mechanical property of the filtration module in order to confirm the resistance of the filtration module while operating at very high pressure forces. Third, the paper describes the configuration of the cross flow filtration module (materials used, pipes, pump and membrane cell).

Fluid dynamic modeling of the module

Domain geometries: The flat cross flow filtration module designed in this research contains a rectangular support in PVC and a frame structure as illustrated in figure 2. A flat sheet membrane is placed inside a 45 cm^2 cell while the feed is sent tangencially through a pipe and pass through the membrane surface. The membrane is placed on a porous surface that allows the collection of the permeate using a collector pipe. An other pipe is connected to the retentate stream in order to collect the rejection the can be recycled to the feed stream. A pressure – Vaccum pump is connected to the system with a pressure range between 1 and 25 bars.

The cross flow filtration module was designed with an optimal position of the membrane cell (membrane chamber) in order to obtain a pressure stabilization while sending the feed inside the system with different pressures. The membrane cell in the system was designed with a height of 2 mm in order to create better aerodynamics conditions inside the membrane chamber during filtration test. In order to avoid any disruption of the flow velocity, the filtration module was designed with 1 input and 2 outputs (figure 1). The system contains a feed stream, the permeate stream and the retentate stream that can be recycled to the feed stream. Figure 2

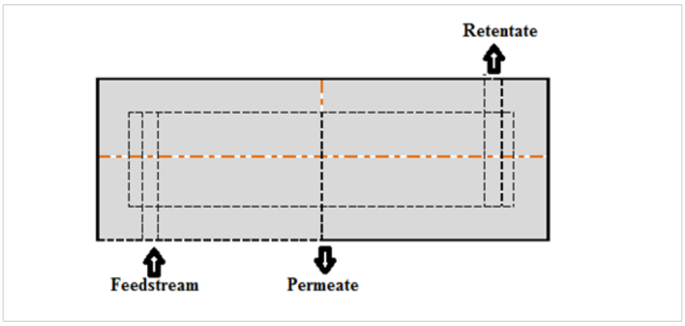

Figure 2: Geometry of cross flow filtration design.

Governing equations: The incompressible Navier – Stokes principles in stationary mode was used to study the laminar conditions in a cross flow filtration module. Concentration polarization and fouling can be studied by using the Navier – Stokes principles mixed with the equation of continuity[6] since the value of the shear rate on the membrane surface can be determined.

$$\nabla \cdot \eta\ (\nabla \mathbf{u} + (\nabla \mathbf{u})^{T}\ ) + \rho(\mathbf{u}\ \cdot\ \nabla)\mathbf{u} + \nabla p = 0 \qquad (1)$$

$$\nabla\ \cdot\ \mathbf{u} = 0 \qquad (2)$$

Boundary conditions: For the simplified geometry, the feed stream boundary condition was set as a laminar flow of about 1 m/s as flow velocity. It has been shown that the laminar conditions can be determined by using the Renolds number (Re=2000), while for two parallel plates that contains the membrane cell (membrane chamber), the characteristic dimension is equal to twice the distance between two plates. Figure 3

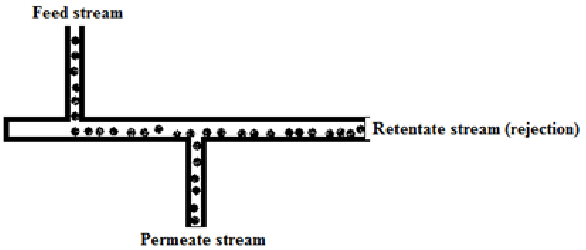

Figure 3: Simplified 2D geometry of the flow domain.

Mechanical modeling of the module: The principle of "solid, stress – strain" was used to investigate on the mechanical property of the designed cross flow filtration system. It has been found necessary to determine if the inserts that were used to place together the two plates of the module were correctly fitted. It was aslo necessary to make sure that the holes that have been drilled on both plates did not excessively debilitate the pieces. The cross flow module was designed to work at a maximum pressure of 50 bar. However, a certain security factor range was taken in consideration during the conception of the module.

$F/A=Y\, e/L$ (3) Where,

F is the force
A is a cross sectional area
Y is the yound modulas
e is the extensión
L is the length

Domain geometry

In this module conception, two different domains were designed, the module contains an upper plate in perspex that is pressed on top of the lower plate (the base) in PVC. The fluid domain was separately calculated and designed. The two plates that form the cross flow filtration module are pressed together with 8 inserts in order to support the pressure that can be used to send the fluid during the filtration test. The upper plate of the system contains the input (feed stream) while the lower plate (base) contains the membrane cell, the permeate stream and the rejection channel.

Boundary settings of the system: It is well known that during the filtration test the inserts apply the force at washers in order to maintain the two plates of the module pressed together. Therefore, the boundary condition was set as a Z- displacement constraint (R_Z=0) in the areas that are in the contact with the washers.

Fluid dynamic results: The space that exists between the two plates of the module (membrane cell) is a very important area that can be used for membrane characterization and pressure measurement. Therefore, the 2D simplied geometry that has been described below was used to investigate on the flow profile stabilization. It has been discovered that the change of direction occurs when the flow enters the feed side to the membrane cell (Figure 3). It has to be noticed that the configuration of the membrane chamber should be also designed in order to facilitate the pressure measurement. From figure 3, the fully developed scenario shows that velocities profile is parallel to the membrane surface for a channel of height H, it can be observed that the velocities profil has a parabolic shape and always depends on the average velocity V_t. This scenario can be described by the couette flow equation:

$$V_t(Z) = 6V_t\,[(Z/H)-(Z/H)^2] \qquad (4)$$

This profile of velocities can be compared with those observed after the Groove that occurs inside of the pressure zone for several schenarios inside the pressure chamber. These profiles of velocities can be developped by using the line – extrusion diagram. It has been discocered that at the profile of velocities obtained at 9–10 mm behaves almost like a laminar flow on the membrane surface.

Mechanical test of the system: The mechanical test has revealed that both plates that form the cross flow filtration module remain pressed during the filtration process with higher pressures. It also confirmed that there won't be any expectation of excessive deformation of the membrane cell where the seal has been placed.Consequently, the filtration module remains mechanically stable.

Conclusion

This study was conduced in order to redesign a cross flow filtration module that intended to minimize fouling, concentration polarization and pressure drop that during the filtration process with a membrane separation module. The results obtained provided more informations about the domain geometry of the system and the materials that need to be used to design and improve the the module properties. It has been revealed that fouling and concentration polarization can be overcome by controling the flow velocity which depends on the domain geometry, boundary sittings and the membrane cell dimensions inside the module. Besides, the mechanical test of the designed module has proved that the diameter of the plates that were used to conceive this module are able to support a ceratin range of pressure.

References

1. Mulder, M. Basic principles of membrane technology (Transport in membranes). (1996) Kluwer Academic Press, Netherlands 210-278.
   Pubmed | Crossref | Others
2. Gozálvez-Zafrilla, J.M., Santafé-Moros, A. Aplicaciones del análisis mediante elementos finitos a la tecnología de membranas. (2008) Proceedings of the Spanish COMSOL Conference, Madrid, Spain.
   Pubmed | Crossref | Others
3. Lyster, E., Cohen, Y. Numerical study of concentration polarization in a rectangular reverse osmosis membrane channel: Permeate flux variation and hydrodynamic end effects. (2007) Journal of Membrane Science 303(1-2): 140-153.
   Pubmed | Crossref | Others
4. Gozálvez-Zafrilla, J.M., Santafé-Moros, A. Effect of backflushing on a particle inside a pore of a microfiltration membrane. (2007) Proceedings of the COMSOL Users Conference in Grenoble 2: 854-858.

Pubmed | Crossref | Others

5. Balannec, B., Gozálvez-Zafrilla, J.M., Delaunay, D., et al. Flow modeling in a flat membrane module. (2007) Proceedings of the European COMSOL Conference, Grenoble France.
Pubmed | Crossref | Others
6. Gozálvez-Zafrilla, J.M., Santafé-Moros, A. Nanofiltration Modeling Based on the Extended Nernst-Planck Equation under Different Physical Modes. (2008) Proceedings of the European COMSOL Conference, Hannover Germany.
Pubmed | Crossref | Others