Optimization of Reverse Osmosis Performance

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Abstract

A condensed description of my work.

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These people helped me a lot with my work.

Contents

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Introduction

1.1 Background

The Water Technologies department at Baxter develops water systems for use in mixing fluid for dialysis treatments. The water quality is important in order to not harm to the patients when using the final product. The water systems used for water purification are using the reverse osmosis (RO) method as the finest level of filtration. It remove impurities, as salt and inorganic molecules from the water[Company, 2018].

In a RO-system the feed water is pressurized by a pump and forced through the RO-membrane to overcome the osmotic pressure. The RO-membrane is a semi-permeable membrane and let water passes freely true the membrane creating a purified product stream.

The pump in the current system has two purposes, creating a pressure to overcome the osmotic pressure and creating a flow on the reject side of the RO-membrane to prevent aggregation of impurities on the membrane surface.

1.2 Motivation

By using two pumps instead of one in the RO-system it will be possible to control the pressure on the module and the flow on the reject side independently and thus get better possibility to optimize the performance of the RO-system, focusing on reducing impurities and water consumption.

As the current model does not take temperature dependencies in concern, the model will be redesigned in order to handle temperature dependencies.

1.3 Goal

The purpose of this masters thesis is to evaluate the feasibility of replacing the main RO-pump with two pumps, one for controlling the flow through the membrane and one for controlling the pressure.

To achieve good performance it will be necessary to design a realistic model of the system, once the model has been designed and tested a control algorithm is to be developed. This algorithm, should be able to control the flow and pressure over the RO-membrane to maximize the efficiency of the filter while minimizing the amount of waste water that is produced.

The temperature dependencies will be taken in concern in the new model.

Framing of questions

- Is it possible to upgrade the RO-membrane model to include temperature dependencies?
- Is it possible to control the system with two pumps instead of one, which is used today?
- Is it possible to control the two pumps in order to gain better efficiency in reducing water waste, noise or performance? (In comparison with the current system)

1.4 Method

In order to investigate the performance of the current system and to compare it with the new model following steps will be evaluated:

- Research on the RO-membrane that is implemented in the system
- Research on previous work on the field
- Modelling of the system to identify suitable component properties and design of the flow path
- Design of control algorithms
- Control simulations
- Implementation in a test rig to verify the performance of the system
- Run tests to determine the performance
- Improve if possible

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Theory

2.1 Semi-permeable membrane

A membrane is defined as a barrier between two homogeneous phases. The process is a continuos steady-state operation consisting three streams: feed, permeate and reject. Main concern in the process boundary is the semipermeable barrier that selectively allows the passage of some components but not others. [R, 2015]

2.2 Osmosis

The osmosis process occurs when two solutions of different chemical concentration are separated by a semi-permeable membrane. The two different solutions will try to reach equilibrium. The solution with less concentration will have a natural tendency to migrate through the membrane over to the side with higher concentration. Osmosis is a naturally occurring phenomenon and one of the most important processes in nature. The pressure that occurs is called the osmotic pressure. The phenomenon can be seen in Figure 2.1

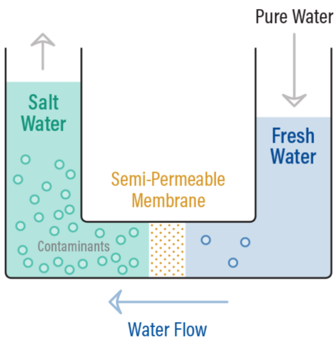

Figure 2.1 Osmosis

2.3 Reverse osmosis

The reverse osmosis(RO) process is the reverse process of the osmosis. When pressure is applied to a semipermeable membrane, the water molecules are forced through the semipermeable membrane and the contaminants are not allowed true. The amount of pressure required depends on the salt concentration of the water. In order to gain reverse osmosis the pressure applied must be greater than the osmosis pressure. The membrane employs cross filtration rather than standard filtration. With cross filtration, the solution passes through the filter with two outlets. One solution passes true the membrane and is called permeate and is the filtered solution.

The other solution can be drained or be fed back into the filtering system. The contaminants build up att the surface area and it is of great importance to try to sweep them away and hold the surface clean. If the contaminants builds up the performance of the membrane will decrease, and cleaning with chemicals or heat water might be necessary[*What is reverse osmosis*]. The phenomenon of reverse osmosis can be seen in **??**. In order to obtain good performace over the RO membrane there

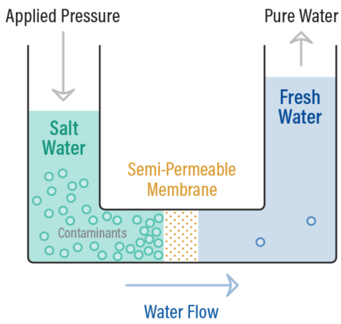

Figure 2.2 Reverse Osmosis

are some parameters that should be taken in consideration when designing a RO system. These are:

- Feed pressure
- Permeate pressure
- Concentrate pressure
- Feed conductivity
- Permeate conductivity
- Feed flow
- Permeate flow
- Temperature

To measure the performance of the membrane there are some important parameters:

- Salt rejection (%)
- Salt passage (%)

- Recovery (%)
- Concentration factor
- Flux

Definitions

$$\textbf{Salt Rejection \%} = \frac{C_f - C_p}{C_f} 100$$

$$\textbf{Salt passage \%} = (1 - SaltRejection\%)$$

$$\textbf{Recovery \%} = \frac{PermeateFlowrate(gpm)}{FeedFlowrate(gpm)} 100$$

$$\textbf{Concentration Factor} = \frac{1}{1 - Recovery\%}$$

$$\textbf{Flux} = \frac{gpmpermeate * 1,440min/day}{nbrOfROelements * \sqrt{FootageOfEachRO}} 100$$

Fouling

Fouling occurs when contaminants accumulate on the surface of the membrane. The fouling contributes to a pressure drop that will decrease the performance of the membrane and cause less permeate flow. Fouling will happen eventually to some extent given the fine pore size of the membrane. A high reject flow and proper pretreatment will extend the operational time between cleaning procedures of the membrane[*What is reverse osmosis*].

2.4 Modeling

2.5 System identification

2.6 Control theory

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Equipment

3.1 Reverse osmosis membrane

3.2 Pumps

3.3 Simscape/Simulink

Simscape is a graphical programming tool within the Matlab simulink environment designed to model and simulate physical systems. A model of the RO-membrane and the flow path was designed using simscape and the simulated system could then be controlled using a control algorithm running in Matlab. The RO-membrane model encorporate separete mathematical models of the most important system dependencies, such as temperature , flow, pressure and conductivity.

The control system was implemented in simulink...

3.4 Water Application Value Engine, WAVE

Water Application Value Engine, WAVE, is a first modelling software program by Dow Water and Process Solutions. The program integrates three of the leading technologies - Ultrafiltration (UF), reverse osmosis(RO), and ion exchange(IX) into one comprehensive tool using a common interface. The program can be used to estimate the performance of UF, RO and IX technologies in water treatment systems. [**DOW**]

3.5 Measurement instruments

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Method/Implementation

4.1 Tests on current system

In order to compare results of the current system and the updated system some test will be done on the current setup. To set up convenient test cases the WAVE software program described in 3.4 is used. Reasonable values for the test cases were set to:

Temperature 5-45 °C

Conductivity 70-2000 µS

4.2 Flowchart investigation

To obtain a system to run tests on some different flowcharts will be considered. The current pump will be replaced by two pumps. Following requirements will be desirable when obtaining a updated model of the flowchart:

- Pressure drop over the membran is high
- Flow through membrane is high

The model shall contribute with the following:

- Permeate conductivity is minimized
- Fouling on the membrane is minimized
- Temperature dependencies will be taken in concern
- Waste water going through drain is minimized

4.3 Modeling

4.4 Design of control algorithms

4.5 Control simulations

4.6 Implementation test rig

4.7 Improvements

5

Results

5.1 Test on current system

Using WAVE program following test cases were evaluated:

Testcases			
Case	°C	μS	Results
1	5	AFG	004
2	5	ALA	248
3	5	ALB	008
4	10	DZA	012
5	10	ASM	016
6	10	AND	020
7	15	AGO	024
8	15		
9	15		
10	20		
11			
12			
13			
14			
15			
16			
17			

5.2 Flowchart investigation

5.3 Modeling

5.4 Design of control algorithms

5.5 Control simulations

5.6 Implementation test rig

5.7 Improvements

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Discussion

discussion

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Conclusion

Bibliography

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