Control of a Reverse-Osmosis Water Desalination System using PI Controller

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Abstract— This work focuses on the design and simulation of a controller for a reverse-osmosis (RO) water desalination system to compensate for the set point changes in feed water supply. A PI controller is designed and its parameters are calculated to minimize the error and to produce an optimum response. This controller is then implemented on the RO system and its set-point tracking capabilities are evaluated.

Key words: Reverse-Osmosis (RO) Membrane, PI Controller, Set Point

I. INTRODUCTION

Reverse-osmosis (RO) membrane desalination is one of the leading methods of water desalination now a day. High efficiency and low cost are the main reasons for its wide spread use, while the lack of fresh water sources helped in further development of this technique [1]. To get the satisfactory response from a RO desalination system it is essential to maintain the desired operating conditions. The changes in operating conditions can have drastic effects on system performance like decreased water production, permanent membrane damage etc.

To reduce the effects of variable operating conditions a robust control is a must. To achieve the desired product quality automation of the plant is very important. The existing industrial RO desalination plants primarily use proportional and proportional-integral (PI) controllers to adjust production flow and feed pumps [2]. These control strategies are able to produce consistent product flow rate, they may not provide an optimal response according to the set-point variations. This problem arises due to the absence of any direct linkage between the two controllers used in these desalination systems, as the controllers cannot adjust automatically with respect to each other according to the variations in operating conditions.

Therefore, efforts have been made to compute the effectiveness of a unity feedback PI controller via Simulink simulation. A PI controller is simulated and its gain parameters are adjusted for optimum response. This controller is then used to make changes in the retentate flow rate by adjusting the retentate valve. An efficient operation of retentate valve is required because the retentate flow rate along with the feed flowrate control the clean water production rate. Thus in this work the set point of PI controller of retentate valve is made proportional to the feed flow rate and also shown to possess good set-point tracking capability.

II. BASIC RO SYSTEM MODEL

A fundamental RO desalination system is shown in this section which includes all the basic elements of UCLA’s (University of California, Los Angeles) experimental RO desalination system. As shown in Figure 1, the feed water to be treated enters the high pressure pump, this pump has a variable frequency drive (VFD), and it is pressurized to the system pressure (Psys). This pressurized stream of feed water then enters the RO membrane, there it is separated into two parts: permeate and retentate. Permeate is the low-salinity product with velocity vP while retentate is the high-salinity waste with velocity vR. The pressures downstream the actuated valve and at permeate outlet are taken equal to the atmospheric pressure.

![Image](https://example.com/image)

Fig. 1: Basic RO system [3].

This model is developed by considering two balances: mass balance for the overall system and energy balance across the actuated retentate valve [4]. Assumptions that are considered during model development of the system model include: water is an incompressible liquid; the plane of operations for all the system components is plane so that the potential energy terms due to gravity could be neglected.

The energy balance taken around the retentate valve leads to the following differential equation:

\[
\frac{d v_r}{d t} = \frac{f_{sys} A_p}{\rho v} - \frac{A_p v_r^2}{2} \frac{d \Delta p}{d v} \quad (1)
\]

Here \(P_{sys}\) is the system pressure, \(v_r\) is the retentate flow velocity, \(A_p\) is the cross-sectional area, \(\rho\) the liquid density, \(V\) the system volume and \(e_{rv}\) is the retentate valve resistance. The mass balance taken around the entire system leads to the equation given below:

\[
v_{f_r} = v_{p} + v_{r} \quad (2)
\]

Here \(v_p\) is the permeate flow velocity and \(v_r\) is the feed flow velocity. The expression for the system pressure is given by:

\[
P_{sys} = \frac{\rho A_p}{A_m K_m} (v_r - v_p) + \Delta \pi \quad (3)
\]

Here \(A_m\) is the membrane area, \(K_m\) is the overall mass transfer coefficient of the membrane and \(\Delta \pi\) is the osmotic pressure.

The retentate valve resistance \(e_{rv}\) is related to the actuated retentate valve position by an equation that can be approximated as [5]:

\[
O_r = \mu \ln e_{rv} + \phi \quad (4)
\]

Here \(\mu\) and \(\phi\) are constants whose value depends on the valve properties.

III. CONTROLLER SIMULATION AND RESULT

In this work the actuated retentate valve is to be controlled by a PI controller, the response of this controller is made...
sensitive to the percentage change in the feed flow rate. In the industrial plants the retentate valve controller is independent of the changes in the feed water flow rate, due to which this system lacks in the relative performance of the controllers of VFD (variable frequency drive) and the retentate valve. By making retentate valve controller sensitive to the percentage change in the feed flow rate the performance of the plant can be optimized. At first a PI controller is simulated and its time constants are adjusted for an optimal response. Fig. 2 shown below depicts the simulation block diagram of a basic PI controller:

Fig. 2: Simulated diagram of PI controller

This controllers response is calculated for the proportional time constant $K_p = 0.01$ [3] and the integral time constant $K_i = 5$ ($K_i$ is varied in the above simulated controller and the desired response is first seen at $K_i = 5$). The input is varied between 1.5 and 0.5 and the output of the controller is found to follow it. The controller response is shown below:

Fig. 3: The PI controller response for the input change between 1.5 and 0.5.

The input of this controller is then made to vary according to the percentage change in the input signal. The percentage change in the input signal is given by the equation below:

$$\Delta R = \frac{R_i - R_{sp}}{R_{sp}} \times 100$$  \hspace{1cm} (5)

Here $\Delta R$ is the percentage change in the input signal (feed flow rate), $R_{sp}$ is the set point value of the input signal while $R$ is the current value of the input signal.

The input signal is simulated to show a variation from +50% to -20% of the set point value, which is taken to be 1 i.e., the value of input changes from 1 to 1.5 and then to 0.8.

Fig. 4: The percentage change in input as shown relative to the change in input signal from 1 gpm-1.5 gpm-0.8 gpm w.r.t. the set point at $R=1$

This input is then applied to the controller as shown in the figure given below:

Fig. 5: Linkage between the feed flow rate and the PI controller of the retentate valve

The whole controller setup (simulation) including the input variable, its conversion in the percentage of set-point value ($R_{sp}$), the PI controller (under study) and the output (changed according to the variation in the input signal), is shown in Fig. 6 given below:

Fig. 6: Simulated block diagram of the controller under study.
The response of this controller to the previously selected input is shown below-

![Graph](image)

Fig. 7: Variation in the input signal (above) and the response of the controller (below) corresponding to the above signal. The Y-axis shows the changes in feed water flow rate and the retentate flow rate in gpm (gallons per minute) and the X-axis shows time in sec.

The above scope display shows the change in the input (the feed water flow rate) and the second display shows the response of the controller to this change. The output of the controller is converted back into its absolute value which can mathematically be represented as:

\[ C = C_{sp} \left(1 + \frac{AR}{100}\right) \]  

(6)

Here \( C_{sp} \) is the set point chosen for the output and in this work it is taken to be ‘1’.

The scope display shows the output waveform of the controller and it is found that the output of this controller follows the changes in the input. So it is clear that by applying this controller to the retentate valve the retentate valve position as well as the retentate flow rate can be made proportional and hence can be adjusted according to the changes in the feed flow rate automatically.

IV. CONCLUSION

In this work, a controller is simulated for the retentate valve, capable of varying its output according to the percentage change in the feed water flow rate. At first a controller is simulated and its parameters and selected for a good response it is then implemented to the percentage change in the input. The controller is found to follow the changes in the input satisfactorily. Since a relative relationship between the feed water flow rate and the retentate flow rate is needed for the satisfactory performance of the RO water desalination plant.

REFERENCES


