ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Reverse Osmosis (RO) Desalination systems using PID tuning.

Asuntha[1], Indrajit Jana[2], Selvam K[3], Andy Srinivasan[4], Joan of Arc X[5]

[1] Assistant Professor, Dept. of EIE, SRM University, Chennai, Tamil Nadu.
[2] PG student [ECE] Dept. of ICE, SRM University, Chennai, Tamil Nadu.
[3] Assistant Professor, Dept. of Chemical engineering, SRM University, Chennai, Tamil Nadu.
[4] Professor, Dept. of E&I, Valliammai engineering college, Chennai, Tamil Nadu.
[5] Assistant Professor, Dept. of EIE, SRM University, Chennai, Tamil Nadu.

ABSTRACT

Reverse Osmosis (RO) Desalination systems is a practical method for providing fresh drinking water, in a remote off-grid communities. It is one of the good and advanced process for desalinating sea water and brackish ground water. Reverse Osmosis (RO) desalination unit model is considered as Multi Input Multi Output (MIMO) process. The relations between the input and output variables are used as transfer matrix form. Reverse Osmosis (RO) Desalination process is an energy intensive method, high efficiency and the power is driven by using Photo-Voltaic (PV) panels. Increasing the efficiency of RO desalination system of PI, PID controller is turned by using Ziegler-Nichols (Z-N) tuning method and shows the better control performance.

Keywords: Reverse Osmosis (RO), MIMO process, Modelling, PI,PID controller

Corresponding author

INTRODUCTION

Motivation:

The demand of fresh water is a great problem in the all over world which increases the world population day by day. Fresh water is one of the important elements for supporting humans and animals life and industry purpose also. The main sources of fresh water is sea water and brackish ground water. Reverse Osmosis (RO) desalination systems is one of the practical method for providing the fresh drinking water [1].

Reverse Osmosis (RO) is an energy-intensive method, where require the about 4 kwh of energy to desalinating the per cubic meter of water [2]. First time Reverse Osmosis (RO) process are operated by using the diesel generator, in the remote off grid area. But these create major problems such as, high radiation in many places and more consumption of diesel fuel, which in turn increases the diesel cost. To overcome this problem, solar panel is introduced with Reverse Osmosis (RO) Desalination process, for providing the sufficient power supply. Another advantages is the solar panel is less costly than the diesel generator. Solar panel is a renewable energy source, low maintenance costs and it does not create any air pollution [1,3].

The Reverse Osmosis (RO) desalination process is a very complex method, where we control the flow rate, salt-concentration, temperature and PH from the source water. So it is called as multivariable process. The paper projects, the improvement in the performance of RO membrane and system controlling performance.

1.2 Background and literature:

The efficiency of Reverse Osmosis (RO) Desalination process is increased by controlling PI and PID controller. Many techniques such as Model Predictive Control (MPC), Model Reference Adaptive Control (MRAC), Fuzzy logic, Dynamic matrix programming, Optimization techniques are used to improve the performance of RO desalination process.

H.M. Colquhoun(2010)- Reverse Osmosis(RO) membrane consists of polyamide membrane, where mounted on porous polysulfone layer. The polyamide membrane is highly permeable, which is used to remove ions, particles and molecules from drinking water. It is necceary to remove the chemicals from the source water before desalinating process, because chemicals can effect the Reverse Osmosis(RO) polyamide membrane. Another way is to clean the Reverse Osmosis (RO) membrane, periodically. Thus high pressures of flow rate is needed to clean the membrane.

S.F.Cheah(2004)- Reverse Osmosis(RO) desalination process is to provide fresh water from sea water and brackish water and make the output of fresh drinking water. The source of energy in RO desalination process is Photo-Voltaic (PV) power.

M. Thomson and D. Infield(2005)- Maintaining the fresh drinking water quality is very important, by diverting water product with un-acceptable levels of salt concentration.

S.R. Wenham(2007)- Cooling the Photo-Voltaic(PV) cell produces more electrical power. In Photo-Voltaic(PV) cell, the characteristics of temperature decreases and the output electrical power increases.

G- Mittelman(2009)- There are many methods of cooling the Photo-Voltaic(PV) cell, such as water cooling, air cooling etc. The heat exchanger is mainly used to cool the Photo-Voltaic(PV) panels and concentrating mirror is used to concentrate a large area of sunlight on to a small area.

S.P. Agashichev and K.N. Lootahb(2003)- In the Reverse Osmosis(RO) desalination process, high RO feed water temperature is needed for good performance. Increasing the water temperature in Reverse Osmosis (RO) unit produces more fresh water.

In this paper, Multi Input Multi Output(MIMO) RO desalination systems is presented. We develop the transfer function model and state space model of RO unit. In last section, the simulation results are discussed in detail.

BASIC DESALINATION SYSTEMS

Desalination is a system, where we can easily remove salts, minerals, small particles from the saline water sources. The basic desalination system block diagram is shown in Fig.1.

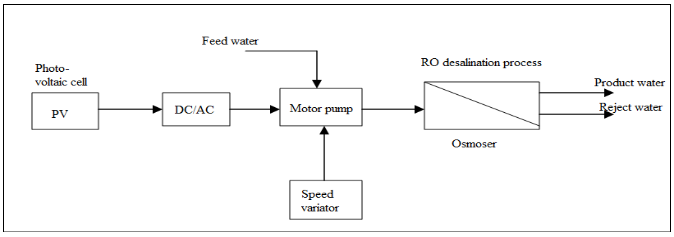

Fig.1. Basic desalination system

The desalination system consist of:

- Photo- Voltaic (PV) cell.
- A DC to AC converter.
- Motor Pump.
- RO desalination Unit.

Photo-Voltaic(PV) cell is source of power supply in RO desalination systems. It is connected in series-parallel combinations, which produces output DC current and voltage. So it is necessary to convert from DC-AC for operating the motor pump.

Three RO modules are used in the desalination unit, which is able to purify the feed water up to 3000ppm. The module capacity is 1500L/d at 800.

3 REVERSE OSMOSIS (RO) PROCESS

Reverse Osmosis (RO) is one of the water purification technology, where the molecules, ions and larger particles are removed from the drinking water by using semi permeable membrane.

The basic Reverse Osmosis (RO) process is shown in Fig.2

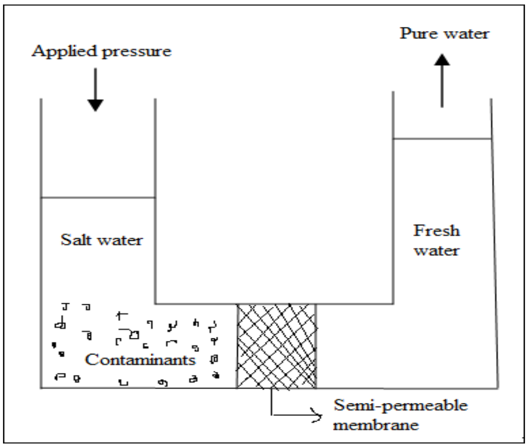

Fig.2. Basic Reverse Osmosis (RO) process

The applied pressure is used to overcome the osmotic pressure and colligative property is used to separate the chemical potential from the solvent. Reverse Osmosis(RO) mainly used to separate the molecules, ions and particles from the drinking water and can be used to remove the many types of bacteria from the fresh drinking water. Reverse Osmosis (RO) process is mainly used in industrial purpose.

Reverse Osmosis(RO) uses a semi-permeable membrane which should not allow the molecules or ions through the membrane holes. The solute is in pressurized side of the membrane and pure solvent is in the other side of the membrane. In normal Reverse Osmosis (RO) process, solvent always moves from low concentration to the higher concentration area. At this time driving force of the solvent reduces the free energy of the systems, when the solvent concentration on both side of membrane is reduced. Always solvent moves to the higher concentration area. An external pressure is introduced to the natural flow of the pure solvent, hence it is called Reverse Osmosis (RO).

The Reverse Osmosis (RO) system uses the large amount of water because of low back pressure. It recovers only 5-15 percentage of water and remaining water is waste, which is the main disadvantages.

DESALINATION UNIT MODEL

MIMO system of Reverse Osmosis (RO) unit state model is shown in Fig.3.

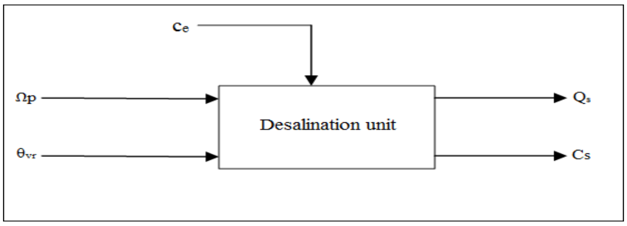

Fig.3. unit static model of desalination systems.

Where,
Q_s is the output product water flow.
C_s is the output product water salinity.
Ω_p is the motor pump angular speed.
Θ_{vr} is the aperture reject brine valve.
C_e is the Salinity feed water.

The input-output model gives the good performance of Reverse Osmosis (RO) desalination systems. The main configuration of the desalination unit model is shown in Fig.4.

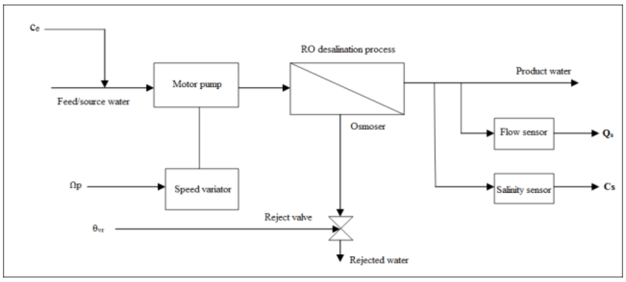

Fig.4. desalination unit model

The relation between the motor pump angular speed and water flow rate is

$$T=K\Omega_p Q$$

Where, K is constant and pressure is P.

$$P=K\Omega_p^2$$

Constant K is depends upon the density of fluid and pump characteristics.

TRANSFER MODEL OF DESALINATION UNIT

Since Reverse Osmosis (RO) desalination system is a Multi Input Multi Output (MIMO) system. Two input variable m=2 and two output variables n=2 are taken the structure of MIMO process is shown in Fig.5.

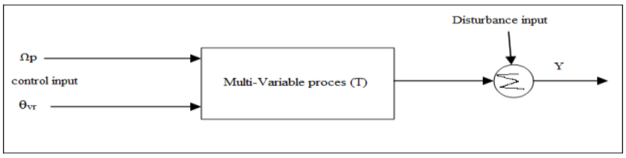

Fig.5. Structure of MIMO process.

Consider the output vector Y, control vector U and the relation between the Q_s, C_s and Ωp, Θ_{vr} are:

$$Y=\begin{bmatrix} Q_s \\ C_s \end{bmatrix} \text{ et}$$

$$U=\begin{bmatrix} \Omega_p \\ \theta_{vr} \end{bmatrix}$$

Transfer matrix T is:

$$T=\begin{bmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{bmatrix}$$

The whole process is described in the following equation: Y=TU.

Now apply the control loops interaction method to get the following models validation relationship.
The expression is denoted by $G_{ij.}$

So,

$$G_{11}=\left(\frac{Q_s}{\Omega_p}\right)_{\theta_{vr},C_e=cte}=\frac{K_{11}}{1+\tau_{11}p}$$

$$G_{22}=\left(\frac{C_s}{\theta_{vr}}\right)_{\Omega_p,C_e=cte}=\frac{K_{22}}{1+\tau_{22}p}$$

$$G_{12}=\left(\frac{Q_s}{\theta_{vr}}\right)_{\Omega_p,C_e=cte}=\frac{K_{12}\omega_{01}^2}{p^2+2\xi_1\omega_{01}p+\omega_{01}^2}$$

$$G_{21}=\left(\frac{C_s}{\Omega_p}\right)_{\theta_{vr},C_e=cte}=\frac{K_{21}\omega_{02}^2}{p^2+2\xi_2\omega_{02}p+\omega_{02}^2}$$

The model parameters values at C_e=3000ppm in shown in Table.1

Table 1. Model parameters values at C_e=3000ppm

Parameters	Values at C_e=3g/L
K_{11}	3.00
τ_{11}	1.10
K_{22}	-0.16
τ_{22}	1.10
K_{12}	-0.28
ω_{01}	1.20
ξ_1	0.30
K_{21}	-0.20
ω_{02}	1.72
ξ_2	0.45

The output product flow is defined as

$$Q_s=Q_e-Q_r.$$

Where Q_r is reject water flow and Q_e is the feed water flow.

STATE SPACE MODEL OF DESALINATION UNIT

The state equations of desalination process is defined as,

$$\dot{X}=AX+BU$$
$$Y=CX$$

Where, $\dot{X}$ = state vector. U= control vector.

$$X=\begin{pmatrix} Q_s \\ \dot{Q}_s \\ C_s \\ \dot{C}_s \end{pmatrix}$$

$$U=\begin{bmatrix} \Omega_p \\ \theta_{vr} \end{bmatrix}$$

The values of A,B,C are obtained from state space analysis method

$$A=\begin{pmatrix} -\frac{1}{\tau_{11}} & 1 & 0 & 0 \\ -\omega_{01}^2 & -2\xi_1\,\omega_{01} & 0 & 0 \\ 0 & 0 & -\frac{1}{\tau_{22}} & 1 \\ 0 & 0 & -\omega_{02}^2 & -2\xi_2\omega_{02} \end{pmatrix}$$

$$B=\begin{pmatrix} \frac{K_{11}}{\tau_{11}} & 0 \\ 0 & K_{22}\omega_{01}^2 \\ 0 & \frac{K_{22}}{\tau_{22}} \\ K_{11}\omega_{02}^2 & 0 \end{pmatrix}$$

Consider the salinity feed water C_e=3000ppm and calculate the values using Table 1.

So the values are,

$$A=\begin{pmatrix} -0.91 & 1 & 0 & 0 \\ -1.44 & -0.72 & 0 & 0 \\ 0 & 0 & -0.91 & 1 \\ 0 & 0 & -2.96 & -1.55 \end{pmatrix}$$

$$B=\begin{pmatrix} 2.73 & 0 \\ 0 & -0.40 \\ 0 & -0.15 \\ -0.59 & 0 \end{pmatrix}$$

$$C=\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

ZIEGLER-NICHOLS (Z-N) TUNING METHOD

Ziegler-Nichols(Z-N) tuning method is applied for finding the value of PI,PID controllers. Ziegler Nichols tuning method is a method which is is based on the frequency response analysis. Another way it is called as ultimate gain method or ultimate cycle method or online tuning method.

This method uses the real data process of the system response. In this paper the Ziegler-Nichols (Z-N) tuning closed loop procedure method is taken for finding the tuning parameters of PI,PID controller. Ziegler-Nichols (Z-N) tuning parameters of PI,PID controller is shown in Table 2.

Table 2. Z-N tunning parameters value.

Controller	K_p	T_i	T_d
PI	$0.45K_u$	$0.83P_u$	-----
PID	$0.6K_u$	$0.5P_u$	$0.13P_u$

Where,
K_p is the proportional gain.
T_i is the integral time constant.
T_d is the derivative time constant.

SETTLING TIME PARAMETERS VALUE

Compare the settling time of PI,PID controller for different motor pump speed in shown in Table 3.

Table 3. Settling time parameters value.

Controller	Ωp=18rps	Ωp=24rps	Ωp=30rps	Ωp=36rps	Ωp=42rps
PI	18.66	18.82	18.65	18.66	18.66
PID	14.82	12.82	14.52	14.68	14.68

EXPERIMENTAL RESULTS

Results and discussion

The output of product water salinity (C_s) and aperture reject brine valve (Θ_{vr}) for different motor pump speed is shown below. According to different motor pump speed, the product water salinity decreases all to aperture reject brine valve. Here input of product water salinity is variable with aperture reject brine valve & various motor pump speed.[10].

In this paper, Fig.6 and Fig.7 shows the response of PI controller for various motor speed such as 18rps,24rps,30rps,36rps,42rps.

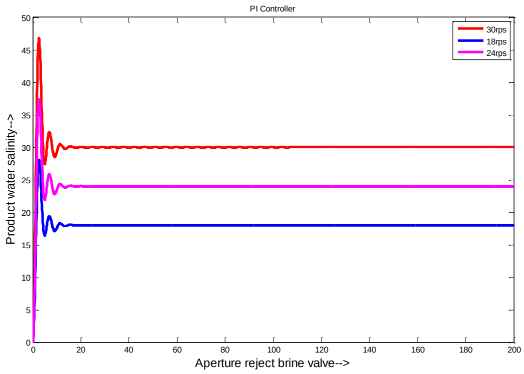

Fig.6. Product water salinity vs aperture reject brine valve for Ωp=18rps,24rps,30rps and various feed salinity.

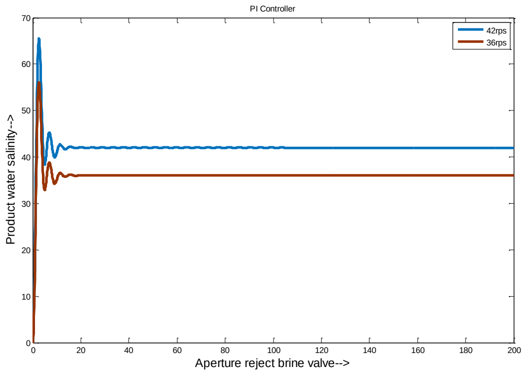

Fig.7. Product water salinity vs aperture reject brine valve for Ωp=36rps,42rps and various feed salinity.

In this paper, Fig.8 and Fig.9 shows the response of PID controller for various motor speed such as 18rps,24rps,30rps,36rps,42rps.

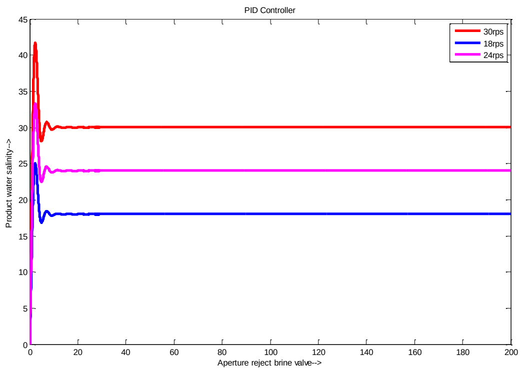

Fig.8. Product water salinity vs aperture reject brine valve for Ωp=18rps,24rps,30rps and various feed salinity.

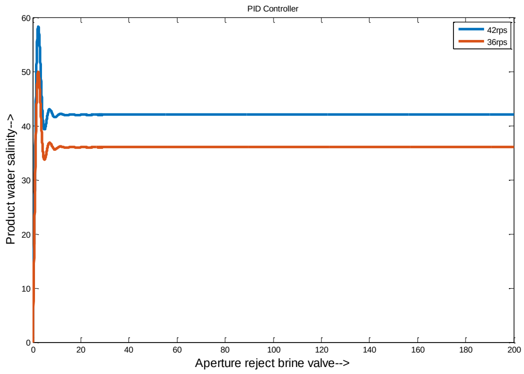

Fig.7. Product water salinity vs aperture reject brine valve for Ωp=36rps,42rps and various feed salinity.

CONCLUSION

In this paper, Multi Input Multi Output(MIMO) Reverse Osmosis(RO) desalination systems models gives the information about output product water flow and output product water salinity. By using state-space model and Ziegler-Nichols tuning method settling time for various motor speed is obtained and compared with PI,PID controller and PID controller gives the better performance for controlling purpose. In future using the Model Reference Adaptive Controller (MRAC) for better performance, because of its nonlinearity the desalination systems.

REFERENCES

[1] A.M. Bilton, R. Wiesman, A.F.M. Arif, S.M. Zubair, S. Dubowsky, On the feasibility of community-scale photovoltaic-powered reverse osmosis desalination systems for remote locations, Renew. Energy 36 (2011) 3246–3256.

[2] E. Tzen , R. Morris, Renewable energy sources for desalination, sol. Energy 75 (2003) 375-379.

[3] NASA, NASA surface meteorology and Solar Energy: Global Regional Data ,National Aeronautics and Space Administration, Atmospheric Science and Data Center,2009.

[4] H. M. Colquhoun, D. Chappell, A. L. Lewis, D. F. Lewis, G. T. Finlan, and P. J. Williams, "Chlorine tolerant, multilayer reverse-osmosis membranes with high permeate flux and high salt rejection," Journal ofMaterials Chemistry, vol. 20, pp. 4629-4634,2010.

[5] S. F. Cheah, "Photovoltaic Reverse Osmosis Desalination System," Report No. 104. Littleton, CO.: ITN Energy Systems, Inc., 2004.

[6] M. Thomson and D. Infield, "Laboratory demonstration of a photovoltaic-powered seawater reverse-osmosis system without batteries," Desalination*,* vol. 183, pp. 105-111, 2005.

[7] S. R. Wenham, M. A. Green, M. E. Watt, and R. Corkish, Applied Photovoltaics.London: Earthscan, 2007.

[8] G. Mittelman, A. Alshare, and J. H. Davidson, "A model and heat transfer correlation for rooftop integrated photovoltaics with a passive air cooling channel," Solar Energy*,* vol. 83, pp. 1150-1160, 2009.

[9] S. P. Agashichev and K. N. Lootahb, "Influence of temperature and permeate recovery on energy consumption of a reverse osmosis system," Desalination*,* vol. 154, pp. *253-266,* 2003.

[10] Ballannec, B., S. Nicolas and B. Bariou (1999). Experimental study and modelisation of reverse osmosis with salt solutesin an unstirred batch cell. Desalination 122, 43-51.