

A METHOD AND SYSTEM FOR OPTIMIZING MEMBRANE CLEANING PROCESS

FIELD OF THE INVENTION

The invention related to the field of reverse osmosis separation process used for desalination and waste water reuse process. More particularly, the invention relates to a method and system for estimating the effectiveness of the membrane cleaning.

BACKGROUND OF THE INVENTION

The reverse osmosis (RO) separation process is becoming increasingly important in the last two decades for desalination and waste water reuse process. RO process is aimed at replacing the conventional energy inefficient processes namely, thermal process & chemical process. This was possible after (i) discovering low pressure and high rejection membrane at lower cost and (ii) integration of energy recovery device (ERD) for recovering energy from reject stream. Even though, membrane separation processes are proved to be energy efficient than the conventional process, the membrane separation has its own demerits such as membrane fouling (deposition of unwanted material at membrane surface due to concentration polarization) i.e. the accumulation of solute molecules near the membrane surface. These materials can be either biological or chemical in nature resulting in bio-fouling or chemical fouling, respectively. As a result, membrane separation process becomes inefficient over a period of operation due to the decrease in production flow rate because of continuous fouling at membrane surface.

In general the RO trains are operated at recommended feed pressure and feed flow rate given by membrane operators, but in real system the optimal operating condition such as feed pressure & flow rate will be changing with respect to membrane operating condition. To overcome this issue, Membrane Performance tool is available to estimate optimal operating conditions for controlling membrane fouling condition.

Although the membranes can be operated at their optimal operating conditions, the fouling at membrane surface cannot be avoided in membrane separation process. Therefore the chemical cleaning and membrane replacement are inherent activities for all membrane

separation processes. Presently the due time for membrane replacement and chemical cleaning are suggested by either membrane expert (consultant) or membrane manufactures.

In order to minimize membrane fouling in RO process, the feed water to membrane is treated continuously with fouling control chemicals such as antiscalants. Though antiscalants dissolve the substances accumulated near the membrane surface and reduce the rate of fouling, the high dosage of antiscalants leads to increase in RO membrane degradation. Therefore, controlled addition of antiscalants to achieve controlled membrane fouling leading to minimal membrane degradation and lower chemical consumption is desired.

Also membrane cleaning chemicals are added to clean the membrane at certain flow rate and concentration as suggested by the membrane manufacturer. Optimizing the chemical flow rate and cleaning cycle based on the current membrane fouling state will reduce the cost of chemicals. This will also help in reducing the production off time due to cleaning and hence increases the RO permeate production.

The membrane fouling / cleaning is poorly understood due to lack of physical understanding about interaction between (i) fouling material and membrane, (ii) among fouling materials, (iii) fouling material and cleaning chemicals, and (iv) between membrane and cleaning chemicals. Since the cleaning phenomena is not well understood, the traditional practice is to keep membrane soaked in cleaning chemicals for a fixed period of time and then bring it back to operation.

Current practice of membrane cleaning is based on recommendations from membrane manufacturers which may consume more cleaning chemicals since the recommendations are given based on feed water quality, and are not based on severity of fouling. In addition, these chemicals are also quite costly. Membrane cleaning process is not well automated and there is an ample opportunity to develop an advanced tool for estimating effectiveness of the membrane cleaning and optimizing the cleaning operation.

The membrane cleaning chemistry and its hydrodynamics are vital in deciding the effectiveness of membrane cleaning. However, it is very difficult to represent these processes mathematically due to their complex nature. Therefore, it requires a simple alternative method to identify the effectiveness of the membrane cleaning.

By estimating the effectiveness of the membrane cleaning, the cleaning chemical consumption and the plant down time can be minimized.

As can be inferred from the above discussion, the membrane cleaning process is time consuming and not optimal due to excessive use of chemicals. This invention is aimed to develop a method and system for optimization of membrane cleaning process

SUMMARY

It is therefore an objective of the invention to optimize membrane cleaning process to provide automatic solution and cost savings by minimizing plant down time and optimal use of antiscalant cleaning chemicals for membrane cleaning. This objective is achieved by a using a method and a system according to the claims 1 and claim 8. Further preferred embodiments are evident from the dependent patent claims.

According to the invention, a method for managing reverse osmosis membrane cleaning process in a plant performing desalination or waste water reuse by operating the reverse osmosis membrane cleaning process for a controlled time for cleaning and with a controlled value of chemical concentration in a chemical liquor prepared for cleaning the membrane, the method comprises of the steps to:

- a) Estimate fouling status of the membrane; and
- b) Determine the controlled value of chemical concentration needed in the chemical liquor and the controlled time needed for cleaning based on the fouling status of the membrane.

The value of chemical concentration and time needed for cleaning based on the fouling status of the membrane are determined using optimization techniques for cost effective and efficient operation of the plant.

The system for reverse osmosis managing membrane cleaning process in a plant performing desalination or waste water treatment by operating the reverse osmosis membrane cleaning process for a controlled time for cleaning and with a controlled value of cleaning chemical concentration in chemical liquor prepared for cleaning the membrane is provided. The system comprises of:

- a) A membrane performance tool to obtain the membrane fouling status
- b) One or more sensors to obtain salt concentration information in the chemical liquor
- c) An automation block to administer concentration of cleaning chemical in the chemical liquor

The membrane performance tool may be based on mathematical or data model, wherein the model utilizes formulations based on physical phenomenon or/and plant parameters including statistical models for computing/estimating membrane fouling status. The membrane performance tool may also be based on direct/indirect measurement techniques (eg ultra sound methods to determine fouling status).

In a preferred variant of the invention, in the method for managing membrane cleaning process, the time needed for cleaning is determined using a function for concentration of salts in the chemical liquor that is obtained with Residence Time Distribution studies.

In another preferred variant of the invention, in the system for managing membrane cleaning process, the automation block used to administer addition of fresh chemical to the chemical liquor has an optimizer to compute optimal value of chemicals and optimal time needed for cleaning.

In yet another preferred variant of the invention, in the system for managing membrane cleaning process, the automation block administers addition of fresh chemical to the chemical liquor through one or more control valves controlling the flow of circulated chemical liquor and the flow of fresh chemical into the chemical liquor.

BRIEF DESCRIPTION OF THE DRAWINGS

The subject matter of the invention will be explained in more detail in the following text with reference to preferred exemplary embodiments which are illustrated in the attached drawings, in which:

Figure 1 schematically shows the RO membrane cleaning system;

Figure 2 illustrates the cleaning reaction kinetics; and

Figure 3 illustrates the architecture of the cleaning automation block

reference symbols used in the drawings, and their meanings, are listed in summary in the list of reference symbols. In principle, identical parts are provided with the same reference symbols in the figures.

TAILED DESCRIPTION

It should be observed that method steps and system components have been represented by conventional symbols in the figures, showing only specific details that are relevant for an understanding of the present disclosure. In the present disclosure, the method steps are used to distinguish one entity (steps) from another entity, without necessarily implying any specific order among the method steps. Further, details that may be readily apparent to a person ordinarily skilled in the art may not have been disclosed and a mention of a term in singular word form (eg cleaning chemical, sensor etc) are intended to also include plural and plural form or the variety generally associated with the term in the art (eg variety/plurality of cleaning chemicals, multiple sensors used in measurement etc).

Embodiments of the present disclosure provide a method and system for estimating effectiveness of membrane cleaning with use of estimation block and optimizing chemical consumption to improve plant down time.

The membrane chemical cleaning system 100 is shown in Figure 2. The membrane chemical cleaning system 100 has a RO membrane 110 that is being cleaned with a cleaning chemical solution and various system components including cleaning chemical tank 120, valves 130, membrane performance measurement tool 140, one or more sensors 150 to measure chemical concentration and cleaning automation block 160 to control the process of cleaning and manage usage of the cleaning chemical.

The cleaning chemical is stored in cleaning chemical tank 120 and it is re-circulated through the fouled RO membrane system 110. During this time there is no regular feed water to the membrane system. The output cleaning chemical from the membrane 110 is again fed to the cleaning chemical tank 120 for recirculation. The concentration of chemical will decrease due to the chemical reaction between cleaning chemical and organic/inorganic salts deposited over the membrane surface. The process temporality is presented in figure 2. To maintain the cleaning chemical concentration in the cleaning chemical tank, additional fresh cleaning chemical is added to the system so as to maintain

is added to the system so as maintain favorable chemical reaction rate. The fresh chemical addition and the chemical recirculation are controlled by the cleaning automation block 160.

The concentration of cleaning chemical in membrane cleaning system is estimated from mass balance and reaction kinetic equations (1- 3) as given below

$$\frac{dV}{dt} = F_{in} \quad (1)$$

$$\frac{dVc}{dt} = F_{in}c_{in} + S_m r_c \quad (2)$$

Kinetic equation for reaction rate

$$r_c = -k_c c^a \quad (3)$$

The equations for initial conditions are as follows:

$$c = c_{int} \quad (4)$$

$$V = V_{int} \quad (5)$$

Where,

V = Total cleaning chemical volume, m³

F_{in}= Inlet cleaning chemical flow rate, m³/s

c= Cleaning chemical concentration at membrane system, kg/m³

c_{in}=inlet cleaning chemical concentration, kg/m³

S_m= membrane surface area, m²

r_c= rate of cleaning chemical reaction, kg/m² s

k_c=reaction rate constant, (kg/m² s) (kg/m³)^{-a}

a = reaction order, (-)

c_{int}=initial concentration of cleaning chemical, kg/m³

V_{int}=initial cleaning chemical volume, m³

The fouling state of the membrane is represented in terms of Hydrodynamic permeability (A) and Solute permeability (B). The temporal behavior of fouling in the membrane is modeled with the following equations:

$$\frac{dx}{dt} = F_{in}(x - x_{\infty}) + r_c \quad (6)$$

The initial condition is given by

$$x(0) = x_0 \quad (7)$$

where,

x = Fouling state of the membrane which could be A and B

x_{∞} = Irreversible fouling state of the membrane which cannot be restored by chemical cleaning

x_0 = Initial fouling state of the membrane which could be obtained from the advanced membrane fouling monitoring solution

The membrane performance tool 140 is either based using an ultra sound sensor to measure fouling or based on a model for fouling or any other method that provides fouling status. The model parameters may be one or more fouling parameters including hydrodynamic permeability, solute permeability, reflection coefficient etc. In addition, the model may use plant parameters such as feed pressure, reject water flow rate, product water flow rate, product water total dissolved solids for estimating fouling status (extent of fouling). The fouling status is used as an input for determining the optimal chemical usage by the cleaning automation block 160.

The cleaning automation block consists of a mathematical model that makes use of measured plant data from the plant control system or other measurement system interfaced with the cleaning automation block to provide directly measured data or data that is estimated based on one or more measured parameters related to the membrane performance or process of chemical cleaning.

In an exemplary embodiment, the extent of fouling in membrane is estimated using the advanced membrane fouling monitoring solution in the following ways (i) by estimating the current fouling parameters from membrane model with the use of online plant measurements and (ii) by comparing the current fouling parameters with those of earlier

cleaning cycles to estimate the membrane degradation right from the start of membrane operation. With this information, the approximate dosage for membrane cleaning chemicals is estimated and the fouled membrane can be initially fed with the estimated amount of chemicals.

During the membrane cleaning process, the salts deposited over the membrane are dissolved in re-circulating liquor and its concentration is to be measured by using suitable sensors (for example sensors like ion selective electrode that measures calcium and sulphate). The model for estimation relies on data from Residence Time Distribution (RTD) studies performed for chemicals with various concentration used for cleaning of membrane and the status of fouling monitored during the studies. The probability distribution functions is thus obtained through the RTD studies. It gives the amount of time the cleaning chemical needs to be circulated in the membrane chamber for effective cleaning and it is a function of the cleaning chemical concentration in membrane chamber. The estimate of the time may be based on a suitable descriptive statistical parameter (example 85 percentile value) such as cleaning chemical concentration.

At the beginning of the process of cleaning, the concentration of the dissolved salts measured at cleaning chemical recirculation path is expected to increase in the chemical liquor as a result of chemical interaction with the fouled membrane. The chemical concentration decreases and reaches an asymptotic value at end of the cleaning. The end time is determined from the RTD data for a particular concentration of chemical and the residue in the membrane (i.e its fouling status). During the process of cleaning, fresh chemical is added in multiple steps to the circulating liquor to increase the rate of cleaning reaction and reduce the time taken for cleaning if the chemical is added in a controlled manner. Therefore, it is desired to optimally balance the addition of fresh chemical and the time for cleaning (down time for the plant) and this function is also carried out by the cleaning automation block 160.

The goal of optimization is to minimize the cleaning chemical consumption and cleaning duration subjected to constraints such as maximum limit on chemical concentration recommended by membrane supplier.

The objective function for optimization is

$$obj = \min_{F_{in}, c_{in}, Q_{in}, t_2} \{w_1 * (t_1 - t_m) * Q_{\Delta t} * C_p + w_2 * \sum_{t_i=0}^{t_2} (F_{in} * t_i * C_c)\} \quad (8)$$

Subjected to constraint

$$C_{int} \leq C_{limit} \quad (9)$$

$$C \leq C_{limit} \quad (10)$$

Where,

t_m = membrane cleaning time as suggested by membrane manufacture, hr

$Q_{\Delta t}$ = permeate production rate in the time $(t_1 - t_m)$, m³/hr

C_p = cost per m³ of permeate water, \$

C_c = cost per m³ of chemical, \$

$t_1 = t_{\frac{dc}{dt} \approx 0}$ i.e. the time at which the cleaning chemical concentration become asymptotic

with respect to time and no further reaction occurs between cleaning chemical and scale deposited over the membrane surface.

w_1, w_2 = weight factor

C_{limit} = maximum chemical concentration recommended by membrane supplier (used as constraint).

$(t_1 - t_m)$ is always maintained as a positive number i.e. absolute number is taken in for the calculations.

The control strategy is formulated with the optimization objective to find the optimal profiles for cleaning chemical flux and its concentration as a function of time, while minimizing the cleaning cost and cleaning time. As shown in Figure 3, the architecture 300 of cleaning automation block 160 consists of (i) models for membrane cleaning (RTD model), fouling state and cost model based on chemical cleaning (310) and (ii) optimizer for minimizing cleaning chemical consumption and cleaning duration (320). The proposed

solution methodology takes into account the current fouling state of the membrane (refer eq. 7) obtained from the advanced membrane fouling monitoring solution to come up with optimal solution for chemical cleaning. The solution may be implemented through flow ratio control for the cleaning chemical liquor controlling the addition of chemical in the liquor based on measurement of salt concentration in the liquor.

The salt concentration data, fouling status data from the components as described above for the membrane cleaning system 100 and also has information about cost of chemicals, cost of plant down time where the cleaning time and fresh chemical addition is estimated from the RTD model present with the cleaning automation block 160. The cost information related to chemicals and plant down time is provided by users and available in the system as illustrated in Figure 3. With these data, the objective function is minimized to achieve optimal values for fresh chemical addition to achieve minimal cleaning time (plant down time). The optimal values are used as the set point in the regulatory control (Eg ratio control) deployed for the membrane cleaning system 100.

Various other modifications and alterations in the structure and method of operation of this invention will be apparent to those skilled in the art without departing from the scope and spirit of the invention. Although the invention has been described in connection with specific preferred embodiments and specifically for optimizing usage of chemicals and the time for cleaning for a RO membrane system, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments or to RO membrane system with components as described in this invention. It is intended that the following claims define the scope of the present invention and that structures and methods within the scope of these claims and their equivalents be covered thereby.

I/WE CLAIM:

1. A method for managing reverse osmosis membrane cleaning process in a plant performing desalination or waste water reuse by operating the reverse osmosis membrane cleaning process for a controlled time for cleaning and with a controlled value of chemical concentration in a chemical liquor prepared for cleaning the membrane, the method comprising of:
 - a) Estimating fouling status of the membrane; and
 - b) Determining the controlled value of chemical concentration and the controlled time needed for cleaning based on the fouling status of the membrane.
2. The method for managing membrane cleaning process as claimed in Claim 1, wherein the estimation of fouling status in the membrane is performed using a mathematical or data model based on physical phenomenon or/and plant parameters.
3. The method for managing membrane cleaning process as claimed in Claim 1, wherein the estimation of fouling status in the membrane is performed using ultra sound measurement.
4. The method for managing membrane cleaning process as claimed in Claim 1, wherein the controlled value of chemical concentration is administered to provide optimal use of chemicals and optimal time needed for cleaning.
5. The method for managing membrane cleaning process as claimed in Claim 4, wherein the optimization is performed considering the cost of chemicals or/and cost related to production loss during plant down time.
6. The method for managing membrane cleaning process as claimed in Claim 1, wherein the controlled time needed for cleaning is determined using a function for concentration of salts in the chemical liquor.
7. The method for managing membrane cleaning process as claimed in Claim 6, wherein the function for concentration of salts in the chemical liquor is obtained with Residence Time Distribution studies.

8. A system for managing reverse osmosis membrane cleaning process in a plant performing desalination or waste water treatment by operating the reverse osmosis membrane cleaning process for a controlled time for cleaning and with a controlled value of cleaning chemical concentration in chemical liquor prepared for cleaning the membrane, the system comprising of:
 - a. A membrane performance tool to obtain the membrane fouling status
 - b. One or more sensors to obtain salt concentration information in the chemical liquor
 - c. An automation block to administer concentration of cleaning chemical in the chemical liquor
9. The system for managing membrane cleaning process as claimed in Claim 8, wherein the automation block to administer addition of fresh chemical to the chemical liquor has an optimizer to compute optimal value of chemicals and optimal time needed for cleaning.
10. The system for managing membrane cleaning process as claimed in Claim 8, wherein the automation block administers addition of fresh chemical to the chemical liquor through one or more control valves controlling the flow of circulated chemical liquor and the flow of fresh chemical into the chemical liquor.