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Development a Coefficient of Performance for Predicat the Reverse Osmosis Desalination Process Performance

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Abstract

this is study for considering how to detect the problems from analysis the operation data in RO plant , in this study we have applied ASTM method 4516 , we have introduced a new parameter for measuring the performance of RO processes, the coefficient of performance, which is considered as a tool for identifying the plant status. The thermodynamic treatment for reverse osmosis processes depends on the balance of chemical potential of the solvents on either side of the membrane. As a general rule, the driving force for the reverse osmosis process and the osmosis process is the difference between the chemical potential of the solvents on either side of the membrane. In reverse osmosis processes, the chemical potential of the solvent in the saline water is increased by increasing the pressure; as we know, the more dissolved solids, there are in water, the less is the chemical potential of the solvent. The effect desired, in reverse osmosis processes, depends on the difference in the solvent chemical potential function. The coefficient of performance is the effect desired divided by the energy required (The coefficient of performance (COP) is defined as the ratio of the theoretical work to the actual work required), and this coefficient of performance gives us a complete description of the reverse osmosis process efficiency, and is a helpful tool for diagnosis of the problems in the process. Keywords: coefficient of performance, data normalization techniques, efficiency, RO process, solvent chemical potential

1. Introduction:

Membrane processes are becoming increasingly attractive as an alternative to conventional water and wastewater treatment. Membrane filtration techniques are very promising for the preparation of microbiologically safe and biologically stable drinking water because of their capacities for removing micro-organisms, and also some inorganic and organic compounds. However, scaling and membrane fouling are causing serious operational problems. Biofouling that is, the growth of biomass and the formation of biofilm on the membrane surface, cause flux reduction and/or increased pressure drop in the nanofiltration (NF) and reverse osmosis (RO) processes. To identify the operational problems the operational data is used. The main parameters for this method are the permeate flow rate (Q), and salt passage (SP). According to the ASTM-D4516 method, examination of these two parameters enables us to discover exactly what has happened to the membrane. The permeate flow rate reflects the quantity of water produced and the salt passage reflects the quality of water produced. Another method is the mass transfer coefficient (MTC) method. This method evaluates the change in the mass transfer coefficients for both water and salt over the time of operation to find out what has happened to the membrane during the operational period. In yet another method, called the coefficient of performance (COP) method, COP is monitored over the operation period. By observing the decline in COP and also the change in the normalized permeate flow rate and salt passage, we are able to identify the exact problems. This is a generic method.

2. Materials and Method:

Calculation method:

The coefficient of performance (*COP*) is defined as the ratio of the theoretical work to the actual work required to produce a mole of permeate water from the feed water. The work is evaluated through the difference in chemical potential of water in the feed and the permeate, since the chemical potential of water is given by. [7,8]

$$\mu_w(T,p,X_w) = \mu_w(T,p_0) + RT\ln(a_w(T,p,X_w)) + \int_{p_0}^{p} v_w(T,p)dp \quad (1)$$

And at the isothermal condition, the chemical potential diffe

$$RT\ln(X_{w,feed} / X_{w,permeate}) + v_w(P_{feed} - P_{permeate})$$

rence (J/mole) between the feed and permeate is given by

(2) A Assuming that the activity coefficient is unity and the molar volume of water is independent of the pressure. The work (J/s) required for the molar permeation rate of water, , is

$$\dot{m} RT\ln(X_{w,feed} / X_{w,permeate}) + \dot{m} v_w (P_{feed} - P_{permeate}) \quad (3)$$

Assumed neglect the effect of the change into the system entropy due to the change in concentration, then energy input into the system (J/s) is

$$Q_{feed} P_{feed} - Q_{concentrate} P_{concentrate} \quad (4)$$

Therefore, the COP defines as the ration of the effect desired which work to the energy input into the system are.

$$COP = [\dot{m} RT\ln(X_{w,feed} / X_{w,permeate}) + \dot{m} v_w (P_{feed} - P_{permeate})] / [Q_{feed} P_{feed} - Q_{concentrate} P_{concentrate}] \quad (5)$$

Based on equation (5), *COP* can be calculated according to the ASTM D 4516 procedure by the following steps [2].

Step 1
Calculate the molar permeation rate of water from the volumetric permeation rate and density of water.

Molar permeation rate of water (mol/s) = standardized volumetric permeation rate (m^3/s) *10^6mole^3/m^3) * 1.0 (g/cm^3) /18.02 (g/mol) (6)

Step 2
Calculate the Total Dissolved Solute (TDS) from the electrical conductivity (EC) for both the feed stream and the permeate stream by using the following equation [12].

$$TDS = 4.16 * EC \quad (7)$$

Step 3
Assuming TDS consists only of NaCl, calculate the molar flow rate of NaCl in both feed and permeate stream using

Molar flow rate of NaCl (mole/s) = Volumetric flow rate (m^3/s) * TDS (mg/L = g/m^3)/58.5 (g/mole) (8)

Where 58.5 is the formula (molecular) weight of NaCl. Since NaCl is fully dissociated into sodium and chloride ions, the molar flow rate of NaCl is considered to be equal to the molar flow rate of Na^+ ion ($\dot{n}_{Na}$) and also Cl^- ion ($\dot{n}_{Cl}$).

Furthermore, the molar flow rate of water, $\dot{n}_w$, is approximated by

Molar flow rate of water (mole/s) = Volumetric flow rate (m^3/s)/Molar volume of water, vow (m^3/mole). (9)

This approximation can be justified since the mole fraction of both Na^+ and Cl^- ions are much smaller than that of water in both feed and permeate.

Step 4
Calculate the mole fraction of water for both feed streams and permeate stream using the following equation.

$$X_w = \frac{n_w}{n_{Na} + n_{Cl} + n_w} \quad (10)$$

Step 5
Next, calculate the coefficient of performance *COP* using equation (5), where the temperature, T, the volumetric flow rate of the feed stream and the permeate stream, Q_{feed} and $Q_{concentrate}$, respectively, and the pressure of the feed stream and the Permeate stream, P_{feed} and $P_{concentrate}$, can be experimentally obtained.

Step 6
Plot *COP* versus time on a graph.

Step 7
The ASTM D4516 procedure also describes the method to standardize the permeate flow and salt passage using the following equations [2]:

$$Q_s = \frac{[P_{fs} - \frac{\Delta P_{fbs}}{2} - P_{ps} - \pi_{fbs} + \pi_{ps}](TCF_s)}{[P_{fa} - \frac{\Delta P_{fba}}{2} - P_{pa} - \pi_{fba} + \pi_{pa}](TCF_a)} * Q_a \quad (11)$$

$$SP_s = [Q_a / Q_s] \times [TCF_a / TCF_s] \times (\frac{C_{fbs}}{C_{fba}}) \times (\frac{C_{fa}}{C_{fs}}) \times SP_a \quad (12)$$

In equations (11) and (12), the last subscripts is and a indicate the actual and standard (initial, t =0) conditions. In equation (11), $P_f - \frac{\Delta P_{fb}}{2}$ indicates the average of the feed and brine (retentate) pressure. Hence, it is quite obvious that the term inside the square brackets corresponds to the driving force for the permeation of water. TCF accounts for the effect of temperature on the permeation rate of water and can be calculated using $TCF = 1.03^{(T-25)}$, where T is temperature (^{o} C). Using equation (11), the flow rate obtained under the actual conditions is normalized to correspond to the initial conditions. Similarly, the % separation obtained under the actual conditions is normalized to correspond to the initial conditions using equation (12).[2]

To identify the problem with the process, we first look at the COP versus time plot to examine whether COP is declining with time. We then identify the period where the COP decline occurs. Next, we will plot to standardized permeate flow decline against time and salt passage against time to find the specific reason for the COP decline. COP seems a good indicator for the membrane state and a helpful tool for identifying the membrane or process problems.

3. . Case study:

To test this method, the data from the brackish water desalination plant located in Klazienaveen, Netherlands, was used. The nominal capacity of the brackish water reverse osmosis (BWRO) plant is 75 m^3/h (500.000 m^3 per year). This test considers only the first stage in the first array, which means that the RO module capacity is 15 m^3/h. The client has a special water quality standard. The requirements for the product water quality are shown in Table 1.[11]

Table (1) Product water quality requirements [11]

Parameter	Unit	Process water
Acidity	**PH**	**5-7.5**
Conductivity	**µS/cm**	20
Chloride	**Mg/l**	5

Raw water (surface water) is obtained from canals near the site. A major issue is the variation in its quality between summer and winter. In summer, raw water is obtained from a nearby lake. This water has a relatively low concentration of iron and organic matter, a low turbidity, and a high concentration of salts. In winter, the quality of the water is quite different, with high iron and organic matter concentrations and a high turbidity. At this time of the year, the water comes from the peat areas in the northeast of the Netherlands and is therefore affected by the peat and humus. Usually, the change between the two water types is gradual and occurs in April and October. Table 2 shows the composition of the canal water. [11]

The process scheme of the industrial plant contains a series of pretreatment steps prior to the RO system in which coagulation is promoted using polyaluminum chloride (PACl).

The PACl dosage was added to adjust the UV/DOC ratio to 2.5 using a UV-monitor on the UF system. PH decrease by adding PACl. The RO system received the UF permeate as feed; however, it was necessary to control the pH of the RO system through PACl dosage to reduce $CaCO^3$ scaling and Al^{3+} precipitation on the RO membrane. Additionally, a low dosage of polyaluminium chloride (PACl) (3-5 $mgAl^{3+}/L$) was needed to prevent serous membrane fouling and allow for a stable ultrafiltration operation with a gross flux of 80 $L/m^2.h$. Figure 1 shows a schematic view of the plant. The data acquired from this plant during 2005 is used to examine the method described above.[11]

Table (2) Canal water composition [11]

Parameter	Unit	Summer	Winter
PH	**-**	**6.3**	**7.5**
Turbidity	**NTU**	**10**	**50**
Suspended solids	**Mg/l**	**10**	**30**
Iron	**Mg/l**	**2**	**10**
Manganese	**Mg/l**	**0.1**	**0.3**
Conductivity	**µS/cm**	**650**	**250**
Chloride	**Mg/l**	**120**	**60**
DOC	**Mg C/l**	**15**	**35**
UV(254nm)	**ABS/m**	**50**	**200**

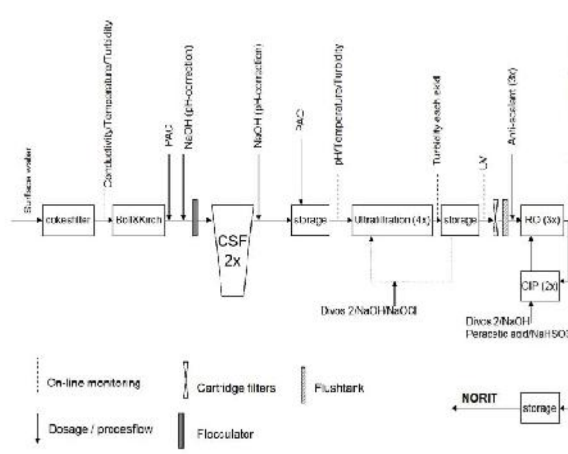

fig.1

The RO membrane characteristics in the Klazienaveen plant are shown in Table 3. A TFC polyamide membrane in spiral wound configuration was used.

Table (3) Membrane characteristics [11]

Criteria	Description
General information	
Supplier:	**Hydranautics**
Type:	**ESPA2-LD**
Diameter:	**8 [inch]**
Area/element:	**37,1 [m^2]**

The RO membrane modules are operated in a cross-flow mode. The system consists of three arrays. As schematically shown in Fig. 2, each array is comprised of two stages; the first stage with three pressure vessels and the second stage with two pressure vessels. Each pressure vessel is 6 meters long and contains 6 elements of 1 meter each. The diameter of the membranes is 8 inches. The product water recovery from the reverse osmosis unit is 75%.

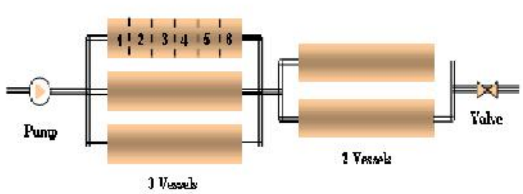

Fig.2 Reverse Osmosis membrane module system

It should be noted that the data from the first stage of the first array is going to be used to test the validity of the method.

5. Results & Discussion:

Figure 3 shows that there was a decline in *COP* during the period from the beginning of January 2005 to the end of July 2005. The *COP* is gradually decreasing during this period due to the increase in the feed pressure to maintain the permeate flux at the fixed level. Figure 4 shows instability in the normalized permeate flow rate with time. It also indicates that the permeate flow rate was above the required 15m^3/h during the entire period.

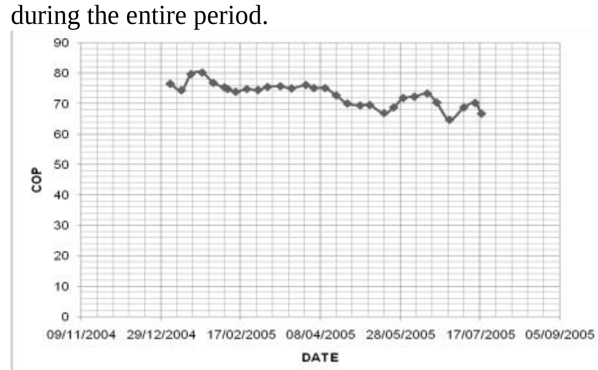

Fig. 3 *COP* change during the one year operation period

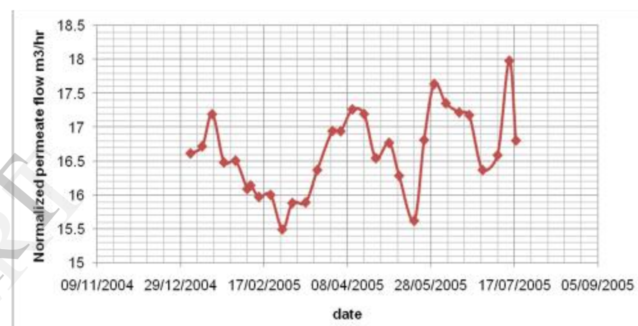

Fig.4 Normalized permeate flow rate during the one year operation period

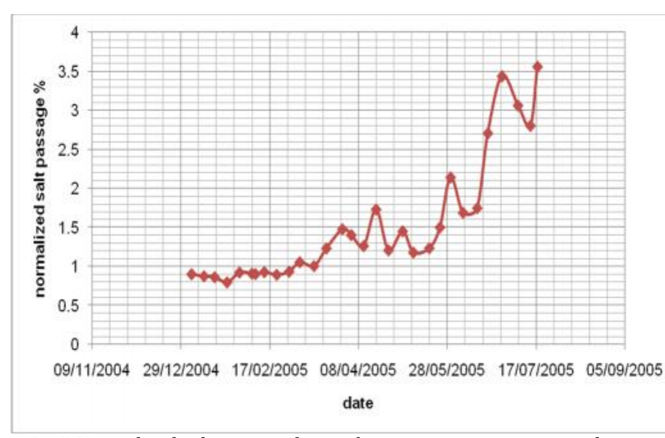

Fig.5 Normalized salt passage during the one year operation period

Figure 5 illustrates the change in the normalized salt passage with time. The normalized salt passage gradually increases during the operational period and eventually surpasses the imposed salt passage limit of 3.5. %. The quality of the permeates is therefore, not as good as desired. This may be due to damage at the dense selective layer of the RO membrane caused by befouling or by the cleaning reagent used. This example shows the usefulness of the method to identify the problem source in the plant operation.First, the COP versus time plot (Fig.3) provides us with general information on whether the plant is working well.Next, the normalized permeate flow rate versus time plot (Fig. 4) shows quantitatively if the permeate flow rate stable and sufficient. If not, it has possibly been caused by membrane clogging or fouling. Furthermore, the normalized salt passage versus time plot (Fig. 5) shows it quality of the permeates sufficiently well. If not, it is possibly due to the damage of the dense layer of the ROmembrane caused by biofouling. The biofouling may also have caused the reduction in the permeate flow rate. In order to make a better diagnosis, an assembly organic carbon ((AOC) measurement is necessary Autopsies of the first and last element of the first stage might also be necessary to measure adenosine triphosphate(ATP), total dissolved carbon(TDC), and heterotrophic plate count (HPC) to confirm that baffling has indeed occurred.

6. Conclusions:

1. In this study there is new development which is The Coefficient of performance COP, which is the useful indicator of whether the desalination system is operating efficiently. It applied as a tool for real time analysis of the plant data to predict for the plant problems and this the new way to understand how the plant work. this indicator gives the real reading for the membrane performance in the plant and it is helpful tool for us to predicate for membrane in early stage ,because this measurement gives the real

2. There is a decline in plant performance over time, and this decline is due to an increase in permeate water TDS.

3. It is useful to standardize the permeate flux to know quantitatively if the to permeate flux is within a desired range during the plant operation. The decrease in the standardized permeates indicates clogging or fouling of the membrane.

4. It is also useful to standardize the salt passage to know if the dense selective layer of the membrane was damaged by biofouling.

5. The poor membrane performance is indeed due to damage of the dense membrane layer due to biofouling, and autopsies of the membrane modules are necessary.

6. LIST OF SYMBOLS:

7.

Aw : Activity of water

Cfa : Feed concentration at actual conditions, mg NaCl/l

Cfs : Feed concentration at standard conditions, mg NaCl/l

Cfba : Feed-brine concentration at actual conditions, mg NaCl/l

Cfbs : Feed-brine concentration at standard conditions, mg NaCl/l

EC : Electrical conductivity （mS/m）

$\dot{n}_w$: Molar flow rate of permeate water (mol/s)

n^{H2O} :Molar flow rate of water (mol/s)

n^{Na} : Molar flow rate of Na^+ (mol/s)

n^{Cl} :Molar flow rate of Cl^- (mol/s)

P:Pressure (kPa)

P_0:Standard pressure (kPa)

$P_{concentrate}$:Concentrate pressure (kPa)

P_{feed}: Feed pressure (kPa)

$P_{permeate}$: Permeate pressure (kPa)

P_{fa}:Feed pressure at actual conditions, kPa

P_{fs}:Peed pressure at standard conditions, kPa

P_{pa}:Permeate pressure at actual conditions, kPa

P_{ps}:Permeate pressure at standard conditions, kPa

$\Delta Pfba$:Device pressure drop at actual conditions, kPa

$\Delta Pfbs$: Device pressure drop at standard conditions, kPa

Qs: Permeate flow rate at standard conditions, m3/sec

Qa: Permeate flow rate at actual conditions, m3/sec

$Q_{concentrate}$**:** Volumetric flow rate of the concentrate stream (m^3/s)

Q_{feed}: Volumetric flow rate of the feed stream (m^3/s)

$Q_{permeate}$**:** Volumetric flow rate of the permeate stream (m^3/s)

R:Universal gas constant

%SPa: Percentage salt passage at actual conditions

%SPs: Percentage salt passage normalized to standard conditions

TCFa: Temperature correction factor at actual conditions

TCFs: Temperature correction factor at standard conditions

T: Absolute temperature, K

T^s : Standard feed water temperature (K)

T^a Actual feed water temperature (K)

TDS: Total dissolved solids (mg NaCl/L)

v_w: Molar volume of water (m^3/mol)

$X_{w,feed}$:Mole fraction of water in the permeate stream (-)

$X_{w,permeate}$: Mole fraction of water in the feed stream (-)

Greek Letters

πfba: Feed–brine osmotic pressure at actual conditions, kPa

πfbs: Feed–brine osmotic pressure at standard conditions, kPa

πpa: Permeate osmotic pressure at actual conditions, kPa

πps: Permeate osmotic pressure at standard conditions, kPa

μ_w:Chemical potential of water (kJ/mol)

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