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Use of DBNPA to control biofouling in RO systems

Ute Bertheas*, Katariina Majamaa, Antonio Arzu, Ralph Pahnke

Dow Biocides, Dow Water Solutions, Bachtobelstrasse 3, 8810 Horgen, Switzerland
Tel. +41 44 728 2832; Fax +41 44 728 3040; email: uhbertheas@dow.com

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ABSTRACT

This paper discusses the use of the non-oxidative biocide 2,2-dibromo-3-nitrilopropionamide (DBNPA) to minimize and/or eliminate problems due to biofouling accumulation and to ensure long-term performance of a RO system. DBNPA is a suitable biocide due to its compatibility with reverse osmosis (RO) membranes. Our aim is to present a better understanding of DBNPA, its rejection by common RO membrane types and the environmental chemistry concepts for residual DBNPA and its by-products in the outlet concentrate stream. The application areas covered are industrial water and off-line drinking water systems. Examples of field studies conducted on full-scale RO systems that use DBNPA will be shown. Also discussed are the data obtained from the analysis that was carried out to determine the degradation of DBNPA in the RO feed and outlet stream. The benefits of using DBNPA for biofouling prevention include reducing the required feed pressure and the cleaning frequency of the RO system. Other benefits are reduced cleaning chemical costs, reduced downtime of the plant and reduced time of the operators. This results in increased output of the plant and reduced operating expenses of the RO operation.

Keywords: RO systems; Biofouling; Biocide; DBNPA; Operating cost

1. Introduction

Many industrial systems depend on reverse osmosis (RO) produced water. These include systems that need water for purely industrial purposes such as refineries, pulp and paper mills. Other common applications for RO are municipal/industrial water re-use and seawater desalination. In the latter examples, the produced water is mostly used for irrigation or potable use.

In all cases the operating cost can be increased significantly by uncontrolled presence of micro-organisms, known as biofouling. 2,2-dibromo-3-nitrilopropionamide (DBNPA) is being used since many years to prevent and remove biofouling in industrial RO systems. In recent years its use has increased in the water re-use and potable water area. Our aim is to present a better understanding of DBNPA and its use, give examples of case studies and economic evaluations.

2. Mode of action of DBNPA

A primary advantage of DBNPA is its rapid kill; depending on the pH, it can be within minutes or hours. DBNPA targets both aerobic and anaerobic bacteria and also shows efficiency against fungi. Handling and disposing of DBNPA are less problematic than for other chemicals and sanitizing agents. Compared to other typical chemical/sanitizing agents, the biggest advantage

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*Corresponding author.

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Table 1
Comparison of biocides for biofouling control in RO systems

	Peracetic acid	Halogens (chlorine, bromine)	Chlorine dioxide	DBNPA	Isothiazolones
Rate of kill	Fast	Fast	Fast	Fast	Slow
Micro-organisms[a]	B, F, A	B, F, A	B, F, A	B, (F), (A)	B, F, A, Y, M
pH	6–8	4–8.5	4–8.4	4.5–8.5	2–9
Biodegradability	None	None	None	Readily biodegradable	Inherently biodegradable
Membrane compatibility	Limited / degradation accelerated by metal ions	No Yes for CA membranes	No Yes for CA membranes	Yes	Yes
Rejection, %				98.5–99.5	
Handling	Problematic Corrosive	Problematic Corrosive	Problematic Corrosive	Easy	Problematic (sensitizer)
Suitability	Limited	No	No	Yes	No for biofouling control Yes for preservation

[a] B: bacteria (aerobic and anaerobic), F: fungi, A: algae, M: mold, Y: yeast
[b] Cellulose acetate based membranes.

Other commonly used non-oxidative biocides are not suitable, mainly due to the fact that they are not compatible with the membranes, such as glutaraldehyde and quaternary amines.

DBNPA has is that it does not damage the thin polyamide layer of the commonly used membranes. Its rejection rate depends on the membrane type; it is between 98.5% for brackish water membranes to 99.5% for seawater mem-branes. The high rejection rates make it suitable for on-line addition.

DBNPA is readily biodegradable when introduced into the environment. DBNPA decomposes by hydrolysis and light. The decomposition pathway is well known and has been published in the past [1]. Excess DBNPA can be easily deactivated with sodium bisulphite and may also be disposed by industrial incineration.

In Table 1 a comparison between DBNPA and other commonly used sanitizing agents is shown. Based on application criteria the suitability of the various chemicals for biofouling control is determined. The table illustrates that the draw back of most oxidizing chemicals is their incompatibility with the membrane, especially the polyamide type membranes.

The non-oxidizers DBNPA, as well as isothiazolones, have good membrane compatibility. For biofouling control isotiazolones are not suitable. They inhibit bacteria growth; however they are slow to kill them. This makes them more suitable for membrane preservation.

3. Usage/applications and dosage of DBNPA

The criteria that determine the treatment parameters are mainly linked to the end-use of the produced water, the type of incoming water, the degree of fouling potential and the size of the plants. The general process descriptions and the role of the pre-treatment are described elsewhere [2]. The following sections describe the use of DBNPA in various end-use applications and give examples of case studies.

3.1. Off-line drinking water systems

For the production of drinking water the off-line use of DBNPA is supported. Prior to dosing the biocide, a membrane train is taken off-line. After flushing for 15–30 min with permeate water DBNPA is being dosed at 20 ppm active biocide and the membranes are soaked under recirculation for 30 min–1 h. After this the membranes are rinsed for approximately 30 min. To make sure that any residual DBNPA left in the permeate water is below the approved levels, specific test kits are available. Offline dosing results in a train shut-down of 1–2 h. Depending on the parameters mentioned above, this procedure is repeated 2–3 times per week. The frequency can be lowered to 1 time per week, if the performance at higher frequency is sufficient.

The El-Atabal RO plant in Malaga, Spain, is producing drinking water with BW30-400 FR membranes from different brackish sources. DBNPA has been successfully used. After optimizing the DBNPA dosage the time period between clean in place (CIP) could be extended from twice a month to once a month. The additional cost for DBNPA is offset by the reduction in cost for cleaning chemicals. In addition, a significant part of operator time was freed to have them available for other tasks.

3.2. Industrial water systems

DBNPA has been for several years on-line in RO plants that produce water for industrial use. Examples are RO plants in refineries, RO plants with sulphate removal membranes on off-shore oil platforms, pulp factories, etc. The on-line dosing is ensured by a pump installed in-front of the cartridge filters before the membranes. It is important to ensure good mixing and eliminate chemical incompatibilities such as sodium bisulphite and activated carbon. Both shock dosing and continuous dosing are possible; typically the dosing regime applied is shock dosing.

Zellstoff Stendal, Germany, is a pulp factory with one of the largest RO plants in Europe (50,000 m^3/d), in operation since February 2004. DBNPA is dosed at the original dosing rate every 3 days and cleaning operations are performed every 3–4 months. After 5 years of operation the performance of the membranes (FILMTEC BW30-400FR) is good and sustainable.

4. Economic evaluations

Membrane fouling will significantly affect the operating cost of a RO plant. The first effect is a substantial increase in the electrical cost to operate the unit. If biofouling remains out of control, it can eventually lead to premature membrane replacement. Additional costs include high expense on labor for additional cleaning, larger amounts of used cleaning chemicals and the down time of the RO plant. A typical operating cost breakdown is illustrated in Fig. 1 [3].

Economic evaluation is prepared for a hypothetical water reuse RO plant with the capacity of 6,000 m^3/h. The expected costs for four different scenarios are compared in Table 2, with various dosages of DBNPA. The energy consumption is calculated with FILMTEC™ Reverse Osmosis System Analysis (ROSA) simulation program using different fouling factors to present the expected fouling rate in each case. The time period taken into consideration is 5 years. The calculations are based assumptions as expressed in the Table 3.

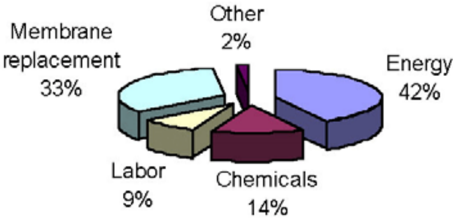

Fig. 1. Operating cost breakdown.

Table 2
Expected costs

Costs	No. DBNPA	DBNPA off-line	DBNPA on-line shock	DBNPA on-line continuous
Plant				
No. of elements	9,000	9,000	9,000	9,000
Permeate production, m^3/h	6,000	6,000	6,000	6,000
Availability (shutdown), %	70	80	85	90
Capital (US $/5 y)	3,375,000	3,150,000	2,925,000	2,700,000
Cumulative annual membrane replacement rate, %	15	14	13	12
Operational	21,600	5,400	5,400	3,600
Operator time, h/year	144	36	36	24
Fouling factor, %	0.6	0.7	0.75	0.8
Cleaning, chemicals (US $/5 y)	360,000	90,000	90,000	60,000
Cleaning chemicals, kg/y	24,000	6,000	6,000	4,000
Cleaning operations, per/y	24	6	6	4
DBNPA (US $/5 y)	0	1,095,000	1,163,438	2,956,500
Consumption, kg/y	0	8,760	9,308	23,652
Dosage concentration, ppm		20	20	
Duration, h		0.5	0.5	0.5
Frequency, days		2	2	
Energy (US $/5 y)	17,870,400	13,455,360	12,614,400	11,983,680
Consumption, kWh/m^3	0.85	0.64	0.6	0.57
Annual requirement, kWh	44,676,000	33,638,400	31,536,000	29,959,200
Total cost	21,627,000	17,795,760	16,798,238	17,703,780

Table 3
Assumptions used in the calculations

Time frame of operation, y	5
Amount of cleaning chemicals, kg/operation	200
Operator time, h/cleaning operation	6
Price per element, US$	500
Cost of operation, US$/h	30
Energy cost, US$/kWh	0.08
Cost of cleaning chemicals, US$/kg	3
Cost of active DBNPA, US$/kg	25

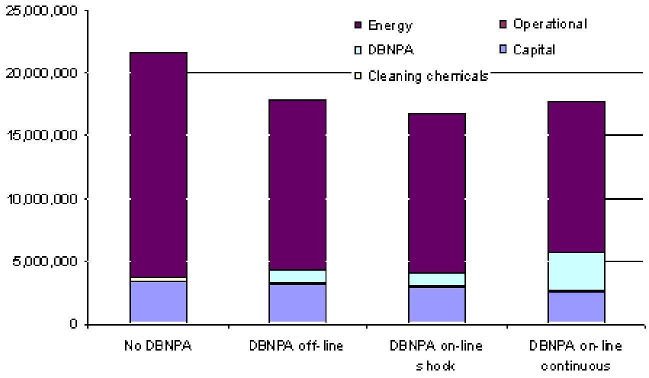

Fig. 2. Cost comparison of a large-scale RO plant.

Fig. 2 shows the comparison in graphical form. The highest impact is, as expected, the energy cost. As can be seen, significant cost savings can be achieved with DBNPA dosing and the on-line shock dosing appears to be the most cost0effective solution for overall cost.

Shock dosing of DBNPA gives an overall cost reduction of approximately 20%, with a similar cost structure for off-line and on-line dosing. However, it must be taken into consideration that, especially for large operations, online dosing is much more practical than off-line dosing. On of the main advantages is freeing up time of operators who can be employed elsewhere in the plant and undisrupted permeate production. Continuous dosing shows the largest energy saving. This is due to the assumption that the fouling rate is significantly decreased compared to the shock-dosing.

5. Application development and Vilaseca pilot plant

The water re-use pilot plant in Vilaseca, Spain, is operated by Dow Water Solutions as part of the of the Spanish governmental subsidized SOSTAQUA R&D project, which focuses on developing technologies towards the sustainability of the urban water cycle. The pilot plant consists of eight elements of 2.5" diameter running in parallel. The feed line is divided into two lines feeding four and four vessels. Feed flow is 300 l/h per vessel. A DBNPA dosing point has been installed after the split; therefore, we are able to compare four vessels dosed with DBNPA and four vessels without.

A range of experiments is planned to develop an application data package. The experiments include online and offline dosing of DBNPA, both shock and continuous dosing, with different types of membranes.

Measurements of DBNPA and its decomposition products will be made in the feed, permeate and reject. These measurements will be carried out over a longer period of time to understand the medium- to long-term behavior of DBNPA in this application. In addition the compatibility and/or effect of DBNPA on typical inorganic ions will be examined. The aim is also to develop a method for online detection of residual DBNPA.

6. Conclusions

DBNPA is the best available technology to prevent biofouling in RO membrane systems. Its benefits are uninterrupted, reliable performance through high capacity utilization, less system down time for chemical cleaning and increased life-time of RO membranes.

A cost evaluation done on a hypothetical water re-use plant shows that savings of up to 20% of total operating cost can be achieved with on-line shock dosing of DBNPA. Continuous dosing results in the highest energy savings, due to a significant decrease in the fouling factor.

The access to the water reuse plant in Vilaseca gives us the capability to develop the application data and generate pilot-plant results to optimize treatment regimes and understand decomposition products in permeate and reject.

The benefits of using DBNPA for biofouling prevention are in reducing the required feed pressure and the cleaning frequency of the RO system. Clear benefits are the reduced cleaning chemical costs, reduced downtime of the plant and the time of the operators. This results in an increased output of the plant and reduced operating expenses of the RO operation.

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