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Cost effective fouling control in (cooling) water intake systems with environmental and operational benefits.

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Abstract
Colonization of intake (cooling) water systems by fouling organisms is a major concern for industries, power stations and desalination plants over the world. Biofouling can result in increased risk of upset conditions and large operational problems, resulting in a reduction of output or even an unplanned shutdown. Such events and operational conditions have a high cost impact. Also, biofouling results in an increased wall roughness and reduction of the inner pipe diameter, leading to a significant head loss in the intake structure. As a result, additional pump capacity is required. To prevent settlement and growth of fouling species, an effective antifouling treatment is a necessity. The global standard industrial practice in coastal areas is application of an oxidative biocide, e.g. hypochlorite, which is dosed at the water intake. Opportunities exist for science-based decisions to optimize site-specific biocide dosing regimes enabling cost-efficient and reliable fouling control, while complying to stringent regulatory discharge limits. R&D in this work field resulted in the dosing technology Pulse-Chlorination® (P-C), which applies a timed based on/off low level chlorine dosing regime. The regime is based on the reactional patterns of local bivalve fouling species. The adaptation of this dosing technology has resulted in significant reduction of chlorine use (up to 50%). It has proved to be more effective in preventing biofouling settlement in intake and cooling water systems compared to continuous and shock dosing regimes. Moreover, it has resulted in major costs savings in both CAPEX and OPEX for, as well as reduced the environmental impact significantly.

Keywords
Biofouling mitigation, chlorination, environmental impact, Pulse-Chlorination

INTRODUCTION

Industries worldwide abstract enormous volumes of surface waters to cool their operation processes, e.g. power plants, (petro)chemical installations, waste incinerators, etc. In addition, desalination plants apply sea water as a source to produce potable water or process water. The larger facilities are mainly located at coastal sites, using sea water for cooling or make-up water. The intake facilities can either be open, directly located on the sea shore, or using a submerged intake pipe with an intake head located below sea level. With sea water, larvae of a variety of marine fouling organisms enter the intake system, such as mussels, oysters, barnacles, hydroids, etc. These macrofouling species can result in major operational problems due to blockage of the cooling water system, e.g. condensers and heat exchangers. To guarantee operational reliability an effective fouling mitigation strategy needs to be applied, usually by dosing of a biocide. To reduce the environmental impact, a balanced dosing regime of biocides needs to be applied to maintain reliable plant operation. Pulse-Chlorination® (P-C) is a dosing method which reduces the amount of biocide dosed up to 50% and secures safe plant operation. This resulted in major operational costs savings and has proven to be a reliable dosing technique which can be applied worldwide.

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BIOFOULING SETTLEMENT

Intake structures and cooling water conduits are in general ideal environments, providing optimal conditions for settlement and growth of foulers. The continuous flow of sea water provides sufficient oxygen and nutrients, the water flow is turbulent, it is dark and there are no predators.

The process for settlement starts with a chemically conditioning of the surfaces to create optimal conditions for colonization by fouling organisms in reasonably standard pattern. Firstly, organic molecules are deposited, followed by colonisation by microorganisms, which in their sessile phase produce ‘slime’ (xPS), creating a so-called biofilm. Hereafter, colonization of the surfaces by other organisms becomes possible. Both the micro fouling and the macro fouling species constitute the overall biofouling community. Clearly, the types of fouling species and growth patterns are dependent on the geographical location, climate conditions and local water conditions such as salinity and water quality and any seasonal changes.

Macro fouling organisms enter the intake system as larvae, which settle on the surfaces and develop towards adults if conditions are suitable. There is a wide range of sessile species which can cause macro fouling problems, such as bivalves, barnacles, hydroids, tube worms, tube building amphipods, bryozoans and ascidians. Especially fouling organisms that cement themselves (barnacles and some oyster species) result in an irreversible increase in wall roughness as after dying, part of the animal remains on the surface. Therefore, it is very important to prevent settlement of macro fouling larvae in the intake and cooling water system from the start of operation. Fouling organisms will settle on the surface of intake pipes and may, in competition for substrate, grow on top of each other forming thick layers.

Of all biofouling species, bivalves (mussels, oysters and clams) and barnacles are known to cause serious operational problems to industrial cooling water systems. Hydroids can also cause operational problems especially when they foul filter systems or form hard layers in waters with high concentrations of sediment. Hydroids can act as a web structure and in this way filter sediment particles to form obstructions. In addition hydroids are known to foul sieves with small mesh sizes. Measures to control bivalve species will also control the other sessile biofouling species depending on their tolerance to the treatment. The growth rate depends on the species, water temperature and availability of nutrients.

IMPACT OF BIOFOULING

A coastal industry that uses sea water for cooling purpose can suffer from biofouling build-up of a potential biomass of up to hundreds of tons within two years. As a consequence, the cooling water flow is interfered due to the decreased diameter size of the pipe and the increased wall roughness. This results in an increased head loss and decreased efficiency for the pumping station (Woods Hole Oceanographic Institution, 1952), (Hall, et al. 1981). The head loss is mainly caused by the riser head, intake pipelines (including chlorination system) and screens.

Both the diameter of the pipeline and the wall roughness are affected by biofouling. The head loss over a pipeline is determined by the flow velocities, wall roughness and local losses. The local losses are small compared with the losses due to the wall roughness and are therefore neglected. In addition, local losses are too specific for a certain system to take into account. The head loss, ΔH, cab be calculated as follows (Idelchik, 1996):

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$$\Delta H = \lambda \frac{L}{D}\frac{v^2}{2g} \quad \text{with} \quad \frac{1}{\sqrt{\lambda}} = -2\log(\frac{2,51}{\mathrm{Re}\sqrt{\lambda}} + \frac{k}{3,71D}),$$

where λ is the friction factor, L the length of the pipe [m], D the diameter of the pipe [m], v the velocity [m/s], g the gravitational acceleration [m/s2], Re the Reynolds number, and k the roughness value [m].

Besides head loss, there is a continuous risk of blockage of condenser tubes, valves, orifices and other constricted places by organisms that become detached. In Europe alone, companies lose millions of Euros due to biofouling, often not quantifiable due to lack of information. An example of fouling in intake systems and condensers is presented in figure 1.

Figure 1 Macrofouling settlements in condenser A (1996) and breech at the intake EFM 1. Cooling water intake was last manually cleaned at September 1994. Walls and floor intake channel were covered with mussels in a layer thickness of max 30cm (Polman, et al. 2010)

BIOFOULING MITIGATION

To prevent settlement of biofouling there are numerous options, e.g. filtration, coatings or biocides. However, most options do not protect the cooling water system completely from settlement of macro fouling larvae. In addition, most treatment options are not capable to mitigate any settled organism. Biocides have proven to be a reliable and effective option to prevent settlement and growth of macro fouling species. In addition biocides are usually capable to mitigate any settled organism.

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Worldwide, the typical industry practice in coastal areas includes continuous chlorination of the seawater with periodic shock dosing. Chlorination of (sea) water results in the formation of halogenated compounds (Chlorination By-Products, CBPs). In previous studies carried out in the 90s no clear negative ecological effect from CBP's was found neither near the outfall of power stations, nor in the far-field (Jenner et al., 1997, 1998) (Taylor, 2006). Although the study did not show clear evidence CBP's resulted in a negative impact, water authorities urged for alternative methods to reduce the amount of chlorine dosed.

The typical industry practise of dosing chlorine (combination of continuous and shock dosing) is not based on ecotoxicological data of targeted species, but is generally based on a post-hoc observation of antifouling efficiency or performed as an attempt to meet the discharge limits of residual biocide concentrations. Shock dosing is applied in the erroneous notion that it prevents fouling species from adapting to continuous chlorination. Such typical dosing procedures are practiced also in the Arabian Gulf. Therefore, opportunities exist for science-based decisions to optimize site-specific biocide dosing regimes, that enable cost-efficient and reliable fouling control while complying to stringent regulatory discharge limits.

CHLORINATION CHEMISTRY IN SEAWATER

In chlorination chemistry a distinction is normally made between free (active/available) chlorine and combined chlorine. Free Oxidant (FO) is present as an equilibrium mixture $HOCl \rightarrow OCl^- + H^+$ (hypochlorous acid and hypochlorite). Combined chlorine is available in chloramines or other compounds having oxidising properties. Total Residual Oxidant (TRO) is defined as the total oxidising capacity (free and combined) which is available after chlorination. Chlorine demand is defined as the difference between the amount of chlorine added and the FO concentration remaining at the end of a specified contact period.

When chlorine is added to sea water, naturally containing 68 mg/L bromide at full salinity, bromide is oxidized and the hypochlorite is displaced by hypobromous acid (HOBr). This reaction is rapid, with 99% conversion within 10 seconds at full salinity and within 15 seconds even at half salinity. Within the Arabian Gulf, where salinities are above the normal 35 ‰, typically varying in-between 39 – 42 ‰ depending upon season in well mixed deep locations, this would further increase the conversion rate. However, since hypochlorite is produced and stored on-site (in a 10 m^3 tank at approximately 500 – 2000 mg/L) prior to dosage there is the opportunity for chlorine dominated chemistry to produce various by-products.

Hypochlorite and -bromite immediately react with suspended and dissolved organic matter within seawater, especially the N-containing compounds. This process is called “chlorine (bromine) demand”. Reactions between N-containing compounds and chlorine produce halogenated amines are referred to as “bound oxidants”. During chlorination in sea- or brackish water, these oxidants provide an extra toxic effect on bivalves by the reaction product bromamines. Bromamines are, in contrast with chloramines, acutely toxic for bivavles. Brominated amines are, more or less, as toxic as hypobromous acid. The production of these chlorinated by-products accounts for using the term TRO in seawater.

In summary, the effective part of the hypochlorite dosing in seawater is the total toxicity of free (bromine) oxidants (FO) and bound (bromine) oxidants (the latter defined as total residual oxidants or TRO). For this reason the chlorine concentration is generally defined by the amount of FO when used in freshwater and TRO when used for either seawater or brackish water.

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PULSE-CHLORINATION®

Pulse-Chlorination® (P-C), is a method for chlorine dosing in once through cooling water systems developed by KEMA in 1998. It is based on the principle that bivalve biofouling species like oysters, mussels and clams, in general have a recovery period after exposure to a chlorination period, *i.e.* following exposure to a chlorine dosing period, bivalves (e.g., mussels, oysters and clams), require time to recover before they can open again fully to restart filtration. P-C is based on this biological observation that bivalves show a distinct recovery period after exposure to chlorinated seawater for a certain time period. Only after this recovery period, they open their valves fully before restarting filtering water for oxygen and nutrients. P-C enhances a cyclic mode of hypochlorite dosing (on / off dosing regime), based on the behavioural response of the specific bivalve to chlorine dosing, thereby taking advantage of this recovery period to delay the restart of P-C. By applying this strategy, bivalves are forced to switch their metabolic mode continuously between aerobic (when open) and anaerobic (when closed). Under these conditions, the target organisms rapidly use their own energy reserves (*i.e.*, glycogen and muscles). In adult specimens this leads to physiological exhaustion and subsequently death. Thus, the effect of P-C upon the target organisms is based on the repetitive too short recovery period after exposure to short successive periods of chlorination.

P-C results in a more rapid effect, *i.e.* mortality of bivalves, compared to the conventional continuous chlorination methods such as continuous low level dosing, often combined with shock dosing. For better understanding of P-C, an example of the valve movement behaviour which shows the reaction pattern of bivalves in general during P-C is given in Figure 2. Typical behaviour of a bivalve in seawater would be represented by valves being fully open most of the time.

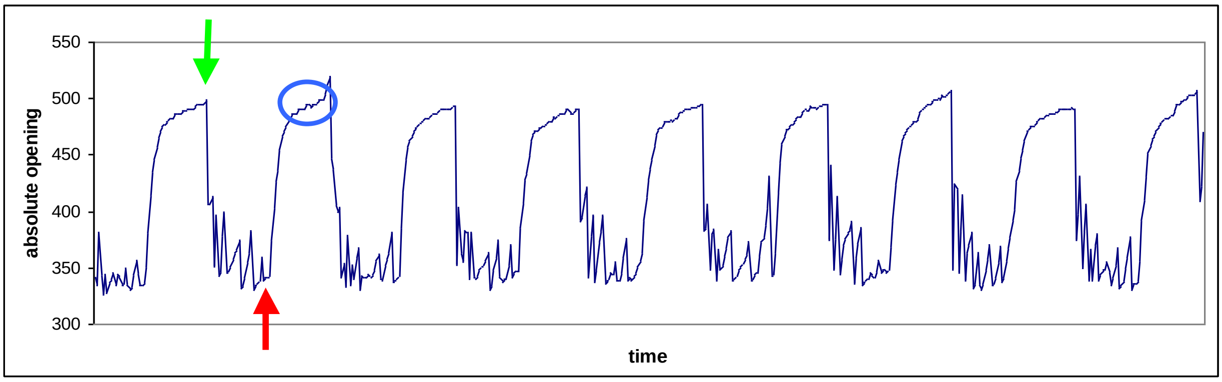

Figure 2. Movement behaviour (opening and closing of the valves) of fouling bivalves detected by a valve movement monitor during a P-C regime. Top arrow (green) indicates the start ('on'), the bottom arrow (red) the timing of stop ('off') of chlorination. The circle indicates the recovery period during which the bivalve slowly opens. Normal behaviour would reflect a continuously open valve position allowing respiration and feeding to occur.

The required effective initial dosage of hypochlorite concentration depends on:

1. the target organism's behaviour, and
2. the seawater quality parameters at the intake.

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In the past 15 years, P-C has proven to result in an effective fouling mitigation. Already in 2000 the method was recognized by the EU IPPC bureau and it was accepted as BAT for once-through systems cooling water system. Several results have been published (Polman 2002, 2011, 2013; Bruijs, 2008,) and (MacDonald, 2009). Overall, P-C resulted in a reduction of the total required volume of chlorine dosed to about 50% compared with previous continuous dosing regimes. The reduced P-C dosing proved also to be more effective in comparison with a continuous dosing using higher levels of FO in the cooling water system. The reason for this increased effect is related to the fact chlorine is not used as a biocide, but rather as a trigger to stimulate the bivalves to become highly active and consume all their energy in a relative short time period. In figure 3 and 4 some examples of cooling water system inspections are presented after dosing P-C.

Figure 3 Maasvlakte Power Station, Unit EFM 1 - return waterbox and intake channel after implementation of P-C

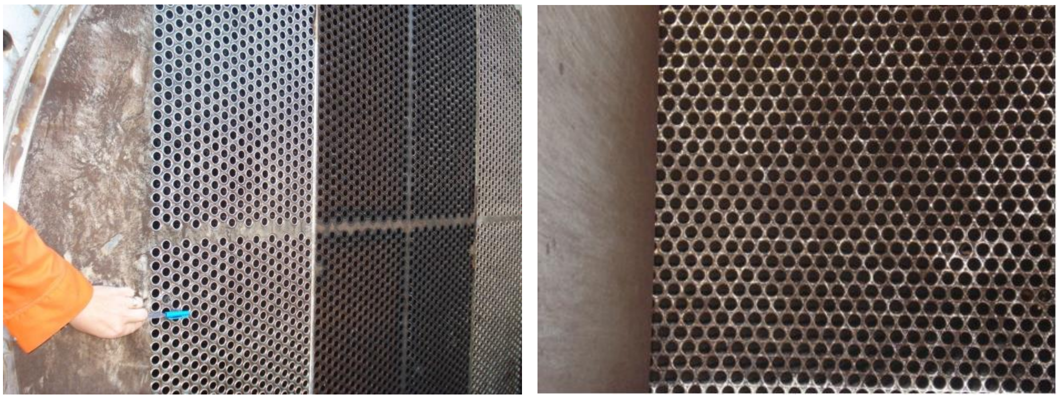

Figure 4 Qatargas Operating Company Limited, Condenser (left) and Tube (right) endplate after implementation of P-C.

The method is universally applicable, but needs to be attuned to local conditions. The overall aim is to ensure an optimal and reliable cooling seawater system and condenser / heat exchanger performance. The application of P-C between 1998 until to-date, resulted in extremely clean condensers and heat exchangers. This was observed at all companies that implemented P-C since 1998. The overall result is better performance of the cooling water system (K-value) and therefore less maintenance is necessary. This in turn allows longer intervals between planned outages and brings down the running costs on the basis of circa € 50.000 per day spread out over three years rather than two years.

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For new to build facilities it is of high importance to start an effective biofouling control method already during the commissioning phase, meaning as soon as a water intake system is started up. Potential biofouling should be taken into account during the design phase of an intake and pumping system. This can be done by selecting the correct chlorination procedure and apply this from the very beginning of operation. Alternatively, create sufficient margin in the system design, such that biofouling will not cause operational problems and additional cost shortly after start up. The easiest way to achieve this is to use intake pipes with relatively large diameters and low flow velocities. The impact of biofouling on operation will be smaller in that case. However, a larger system will have a significant impact on construction costs and low velocities enhance quick colonisation by fouling. Therefore biofouling control by means of optimal prevention method is the most cost-effective way forward.

It is important to prevent the opportunity for biofouling species who cement themselves to the walls have the opportunity to settle and grow. These animals can be killed in a later stage with an effective antifouling treatment but the shells of these animals will stay in place, even after manually cleaning. This result in a permanent increased wall roughness and could have a significant yearly cost impact. In addition it is advisable to

An additional effect of P-C is the reduction of the amount and concentration of oxidants discharged to receiving water body. This is in line with (new) stringent regulatory requirements and lowers the operational costs of related equipment (e.g., electro-chlorinators). Since P-C uses a minimum amount of chlorine it produces a minimum amount of CBPs. Based on its effectiveness and reduced discharge of CBP's, P-C is accepted as Best Available Technique (BAT) under the European terms of the Integrated Pollution Prevention and Control (EU-IPPC) for macrofouling mitigation in once-through seawater systems. It has also gained recognition as an environmentally acceptable method of biofouling mitigation and is officially recognized as such by local regulatory bodies in the Middle East.

CONCLUSIONS

For industrial facilities it is of high importance to control biofouling in cooling water systems since this can result in major risks for operational reliability which can result in unplanned outages. In addition, fouling has an impact on wall roughness and can reduce the pipe diameter of the cooling water system. Especially fouling organisms that cement themselves (barnacles and some oyster species) result in an irreversible increase in wall roughness as after dying, part of the animal remains on the surface. Biofouling results in major costs and makes the control of biofouling of high importance.

The choice of effective fouling control method are limited, most methods have some limitations in efficacy or applicability. Chlorine is at the moment still the most applied biocide to control biofouling and has proven to be efficient and applicable in most cooling water systems. To reduce the use of chlorine and minimise the discharge of residuals or CBPs the dosing technique Pulse-Chlorination has proven to be the best available technique. The adaptation of this dosing technology has resulted in significant reduction of chlorine use (up to 50%) and proved to be more effective in preventing biofouling settlement in intake and cooling water systems compared to continuous and shock dosing regimes and resulted in major costs savings and consequently reduced the environmental impact significantly.

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REFERENCES

Bruijs M. C. M. & Jenner H. A. Cooling water system design in relation to fouling pressure. In: Operational and Environmental Consequences of Large Industrial Cooling Water Systems. Rajagopal S., Jenner H.A. & Venugopalan V.P. (Eds). DOI 10.1007/978-1-4614-1698-2_19. Springer Science+Business Media, LLC 2012.

EU-IPPPC, 2000. BAT-cooling: European IPPC bureau Sevilla, Document on the application of Best Available Techniques to Industrial Cooling Systems, November 2000 (http://eippcb.jrc.es). BREF (11.00) Cooling systems

Hall L.W., et al., 1981, Power plant Chlorination (1st edition), Electric Power Research Institute: Palo Alto, California.

Bruijs M.C.M., Jenner H.A. & Rajogopal S. 2010 Industrial cooling water fouling by Dreissenidae. In: The Zebra Mussel in Europe. Van der Velde G., Rajagopal S. and Bij de Vaate A. (Eds). Backhuys Publishers, Leiden / Margraf Publishers, Weikersheim. 2010, xviii +490pp. ISBN 978-3-8236-1594-1.

Idelchik, I.E., Handbook of Hydraulic Resistance, 3rd edition, Begell House Inc., New York, 1996.

Jenner H, Taylor CJL, van Donk CM, Khalanski M. 1997. Chlorination by-products in chlorinated cooling water of some European coastal power stations. Mar. Environ. Res., 43, 279–293

Jenner HA, Whitehouse JW, Taylor CJL and Khalanski M. 1998. Cooling Water Management in European Power Stations. Biology and Control of Fouling. Hydroécologie Appliquée 10 (1-2), 225

MacDonald, I.A., H.J.G Polman, H.A. Jenner, S.Q.B.M. Quyam. Industrial cooling seawater antifouling optimisation through the adoption of Pulse-Chlorination®, presented at the 2nd International Cooling Water Conference, Doha Qatar from 19 - 20 February, 2009.

Polman, H.J.G. & Jenner H.A., 2002. Pulse-Chlorination®, the Best Available Technique in Macrofouling Mitigation Using Chlorine. In PowerPlant Chemistry 2002, 4(2), 93-97.

Bruijs M.C.M., Polman, H.J.G., Calneggia F. and Jenner H.A. 2008. Optimisation of the cooling water chlorination strategy at Verve energy's power plants Cockburn and Kwinana. presented at the API POWERCHEM 2008 "Power Station Chemistry Solutions for the 21st Century", 25 - 30 May 2008.

Polman H.J.G., M.C.M. Bruijs, L.P. Venhuis, S.A. van Dijk. More than 10 year experience with Pulse-Chlorination dosing regime against macrofouling. In: Heat Exchanger Fouling: Mitigation and Cleaning Technologies. Müller-Steinhagen H. & Zettler H.U. (Eds.). 2nd edition 2011. 464 pages. ISBN 3-934736-20-3.

Polman H.J.G., Bruijs M.C.M., Khan F., Baldwin J. 2012. Results and benefits of the adoption of Pulse-Chlorination® for industrial cooling seawater antifouling at Qatargas, Ras Laffan Industrial City, Qatar. Download pdf at http://www.utilities-me.com/article-2237-case-study-on-the-pulse/1/print/.

Turnpenny A., Bruijs M. C. M., Wolter C. and Edwards N. Regulatory aspects of choice and operation of large-scale cooling systems in Europe. In: Operational and Environmental

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Consequences of Large Industrial Cooling Water Systems. Rajagopal S., Jenner H.A. & Venugopalan V.P. (Eds). DOI 10.1007/978-1-4614-1698-2_19. Springer Science+Business Media, LLC 2012.

González J. A., H.J.G. Polman, L.P. Venhuis, M.C.M. Bruijs & G. van Aerssen.Biofouling Issue, Global Implications and Solutions Linked to Offshore Business: Conference proceedings: “Marine & Offshore Renewable Energy” 26-27 September 2012, London, UK. The Royal Institution of Naval Architects. ISBN 978-1-909024-04-5.

Polman, H.J.G, Verhaart F., Bruijs M.C.M., 2012. Impact of biofouling in intake pipes on the hydraulics and efficiency of pump capcity. Publication in Desalination and Water Treatment 1/20 12, www.deswater.com. 25 June 2012.

Taylor CJL. 2006. The effects of biological fouling control at coastal and estuarine power stations. Mar. Poll. Bull. 53- 30-48.

Woods Hole Oceanographic Institution (1952), Marine fouling and its prevention. (1st edition), Annapolis: U.S. Naval Institute.

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