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Impact of biofouling in intake pipes on the hydraulics and efficiency of pumping capacity

Harry Polman[a,*], Femke Verhaart[b], Maarten Bruijs[a]

[a]*DNV KEMA Energy & Sustainability, Utrechtseweg 310, 6812 AR, Arnhem, The Netherlands*
Email: harry.polman@dnvkema.com
[b]*Deltares Unit Hydraulic Engineering, PO Box 177 2600 MH, Delft, The Netherlands*

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ABSTRACT

Colonization of cooling water systems (CWS) by fouling organisms is a major concern for industries, power, and desalination plants over the world. Biofouling results in, depending on the dimensions of the biofouling species and growth patterns, an increased wall roughness and reduction of the inner pipe diameter. This leads to a significant head loss in the intake structure. To prevent settlement and growth of fouling species, an effective antifouling treatment is required. However, fouling mitigation must be applied from early start of operation of an installation, as several species cannot be fully mitigated (chemically) or removed (physically) after settlement, as some of them (e.g. barnacles, the Japanese oyster and Rock oyster) cement themselves to the surface. This means that even after a physical cleaning, part of the organisms remains on the surface, resulting in an irreversible increased head loss and a decreased pump capacity. To provide some clearance on the impact of biofouling on pump capacity in CWS, two cases have been studied. The results show that nonoptimal fouling treatments result in significant additional annual energy consumption. Even after complete physical cleaning, the remaining head loss is above the design line due to the increased wall roughness and results in decreased pump capacity. The results strongly emphasize the necessity to apply an effective biofouling control during the start-up of a water intake system prior to commercial operation, or to have system design parameters which take into account the irreversible effects of biofouling.

Keywords: Biofouling; Hydraulic impact; Cooling water intake; Pump capacity; Chlorination

1. 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 seawater as a source to produce potable water or process water. The larger facilities are mainly located at coastal areas using seawater for cooling or makeup water. The intake facilities can either be open, directly located on the seashore, or using a submerged intake pipe with an intake head located below sea level. In this article, we focused on seawater intake facilities; however, they will also be applicable for fresh or brackish water cooling systems.

*Corresponding author.

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With seawater, a variety of marine fouling organisms enter the intake system, such as mussels, oysters, barnacles, etc. Intake structures and cooling water conduits are in general ideal environments, providing optimal conditions for settlement and growth of foulers. The continuous flow of seawater provides sufficient oxygen and nutrients, the water flow is turbulent, it is dark and there are no predators.

Upon entering the intake system, fouling organisms can readily colonies the available substrates, e.g. concrete, metal, wood, and glass-reinforced plastic (GRP) surfaces in the intake system, cooling water conduits, condensers, heat exchangers, and cooling tower. A coastal power station (1,000 MW) can build up 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 [1,2]. Furthermore, 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.

This paper presents the results of a study which investigated the relation between biofouling in intake pipes and pump capacity/head loss for two different cases. The systems are located at different locations and have in potential a different variety of biofouling species. Also the magnitude of the intake system differs. First, the two cases are described and some background information on the different foulers and their impact is provided, followed by an overview of the hydrodynamics related to the intake system and the possible methods to prevent fouling. Then the results of the cases are presented and a cost impact is made.

Table 1
Characteristics of the cases

Location	Case 1 Oman	Case 2 Qatar
Number of intake pipes	1	3
Pipe material	GRP	GRP
Diameter pipe (m)	1.6	4.0
Length of pipe (m)	1,200	500
Total cooling water flow (m^3/s)	4.3	66.25
Velocity intake pipeline (m/s)	2.1	1.8
Salinity seawater (‰)[a]	42.9–45.2	37.5
Temperature seawater (℃)[a]	24–36	24–31

[a]Data from [7], Oman: http://www.surf-forecast.com/breaks/Sur/seatemp), Qatar: http://www.qatarembassy.net/environment.asp.

2. Studied cases

Two cases were identified to study the hydraulic impact of biofouling. Both are located in the Gulf region, one of the areas in the world with the highest development of new power and desalination plants. Both cases concern a straightforward submerged intake system which ends into a forebay. After the forebay, the cooling water passes through screening channels, containing bar screens (BS), several stoplogs, and traveling band screens. Hereafter the cooling water enters a distribution chamber, in which the cooling water pumps are installed. The characteristics of both cases are presented in Table 1.

3. Biofouling

As soon as man-made surfaces, such as conduits and pipe work of a cooling water system (CWS), are submerged, the surfaces are conditioned chemically and colonized by fouling organisms in reasonably standard pattern. Firstly, organic molecules are deposited, followed by colonization 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 macrofouling 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.

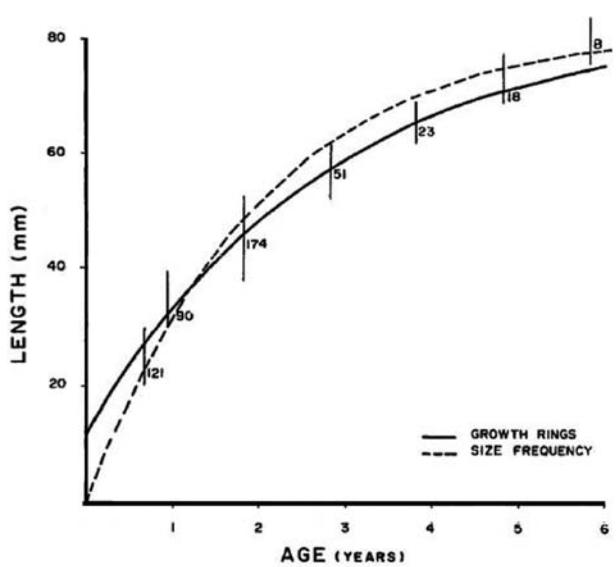

Fig. 1. Growth rate chart *Perna picta*.

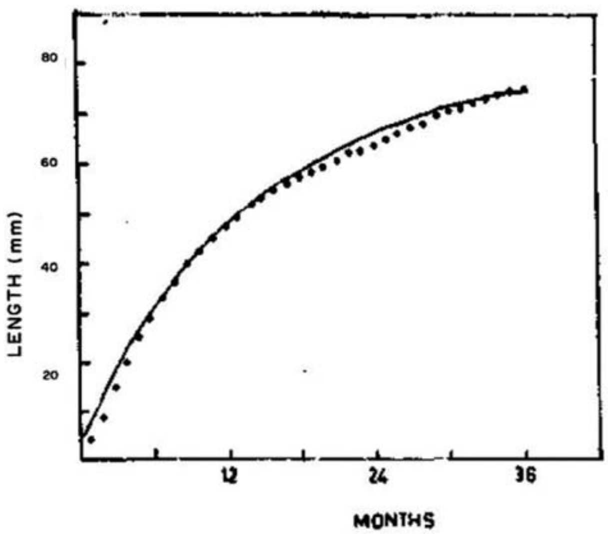

Fig. 2. Growth rate chart *Pinctada radiata*.

Macrofouling 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 macrofouling problems, such as bivalves, barnacles, hydroids, tube worms, tube building amphipods, bryozoans, and ascidians. Of all biofouling species, bivalves (mussels, oysters and clams) and barnacles are known to cause serious operational problems to industrial CWS. Measures to control these 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. Some examples of the average grow rates of different fouling species are presented in Figs. 1–3.

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 macrofouling larvae in the intake and CWS 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. The maximum thickness of the mattress is 19 cm for both cases. In Tables 2 and 3 below, the different fouling species studied at each site and their growth rate in years are presented.

4. Fouling mitigation

To prevent head loss and reduced pump capacity, it is very important to maintain a reliable and efficient operation of seawater intake and cooling systems. There is a variety of methods available to mitigate macrofouling, both chemically and physically, either aimed at prevention of settlement or removal after settlement. Chlorine (as sodium hypochlorite) is to date the most applied method worldwide due to its proven efficacy, relative low costs, and low environmental

Table 2
Maximum growth biodiversity Case 1

	1 year	3 years	5 years	Stacking
Belanus amphrititus	15Ø/20 mm	FG	FG	No
Brachidontes variables	40 mm	FG (50 mm)	FG (50 mm)	Yes
Perna picta	26 mm	50 mm	70 mm	Yes
Saccostrea cucullata	47 mm	FG (56 mm)	FG (56 mm)	Yes

Note: FG = full grown.

Table 3
Maximum growth biodiversity Case 2

	1 year	3 years	5 years	Stacking
B. amphrititus	15Ø/20 mm	FG	FG	No
B. variables	40 mm	FG (50 mm)	FG (50 mm)	Yes
P. picta	26 mm	50 mm	70 mm	Yes
P. radiata	42 mm	FG (70 mm)	FG (70 mm)	Yes

Note: FG = full grown.

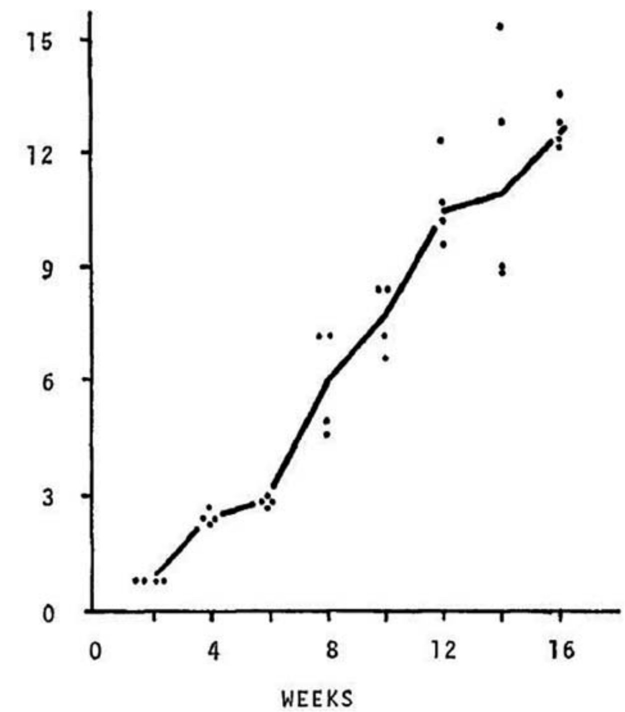

Fig. 3. Growth rate chart *Belanus ampritītus*.

impact if dosed correctly. Typical practice for chlorination in coastal areas includes continuous chlorination combined with periodic shock dosing. Only shock dosing regimes are also applied, foremost at locations/installations where the use of chlorine is restricted, Seawater reverse osmosis systems for example. However, this practice is not based on ecotoxicological data of targeted species, but is merely a post hoc observation of antifouling efficiency, or performed as an attempt to meet the residual biocide discharge limits. Shock dosing is applied in the erroneous notion that it prevents fouling species from adapting to continuous chlorination. Such typical dosing procedures are practiced at numerous locations around the world; however, the efficiency is relatively low. Alternative, optimized methods have been developed to obtain improved cost-effectiveness. Pulse-Chlorination® is a dosing method based on the behavioral reaction of bivalves to chlorine dosing and is a site-specific dosing regime. The dosing technology enables cost-efficient and reliable fouling control, while complying with stringent regulatory discharge limits.

In this study, for each case three different dosing scenarios were studied in relation to the hydraulic impact. In addition, two scenarios are studied in which fouling mitigation is started after 1 year of operation, meaning no biofouling during the first year of operation. The mitigation options which were selected for these cases are Pulse-Chlorination, continuous chlorination, shock dosing (1 h per day), manually cleaned after 1 year operation, and Pulse-Chlorination/continuous chlorination after 1 year of operation. All scenarios are compared with a system in which the intake pipeline is only affected by wear.

5. Fouling impact

The head which should be delivered by the pumps is determined by the head losses in the pumping station and by the CWS itself, including condensers. In this study, it is assumed that only the pumping station is affected by biofouling and not the CWS. If the head loss effect due to biofouling in the pumping station is known, the additional pump energy necessary to overcome the biofouling can be determined.

The head loss is mainly caused by the riser head, intake pipelines (including chlorination system), and screens. For the studied cases, the total head loss is mainly determined by the friction losses in the intake pipelines. The flow velocities in a riser head are low and therefore, the effect of biofouling is relative small. Both BS and traveling band (drum) screens are cleaned continuously (or at least at regular basis) such that fouling occurs only occasionally.

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, is calculated as follows [3]:

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

In which:
λ=friction factor (–); L = length of the pipe (m); D = diameter of the pipe (m); v = velocity (m/s); g = gravitational acceleration (m/s^2); Re = Reynolds number (–); k = roughness value (m).

Both the diameter of the pipeline and the wall roughness are affected by biofouling. The maximum layer thickness is 19 cm (Fig. 4). For the studied cases, this layer thickness is location independent. The wall roughness is determined by the species at both locations and is shown in Tables 2 and 3, varying between 20 and 70 mm. To obtain these values, it is assumed that the biofouling is equally distributed in the length direction and in the cross-section of the pipeline. For the

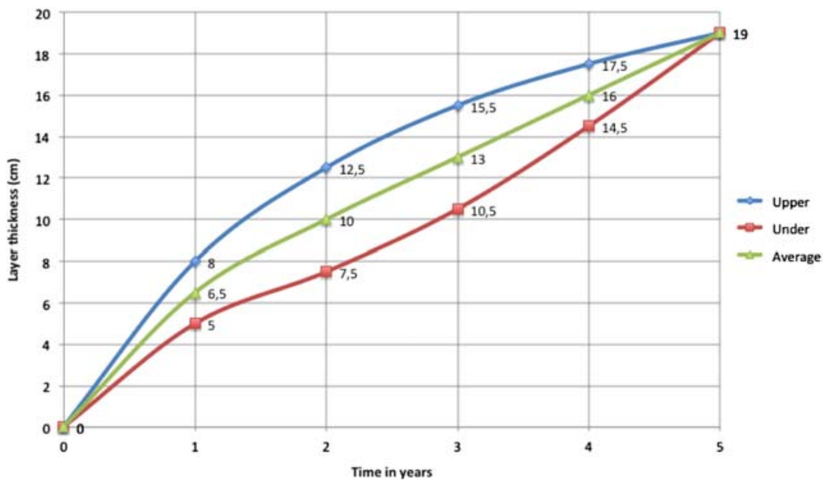

Fig. 4. Development of biofouling layer thickness over the years for both cases.

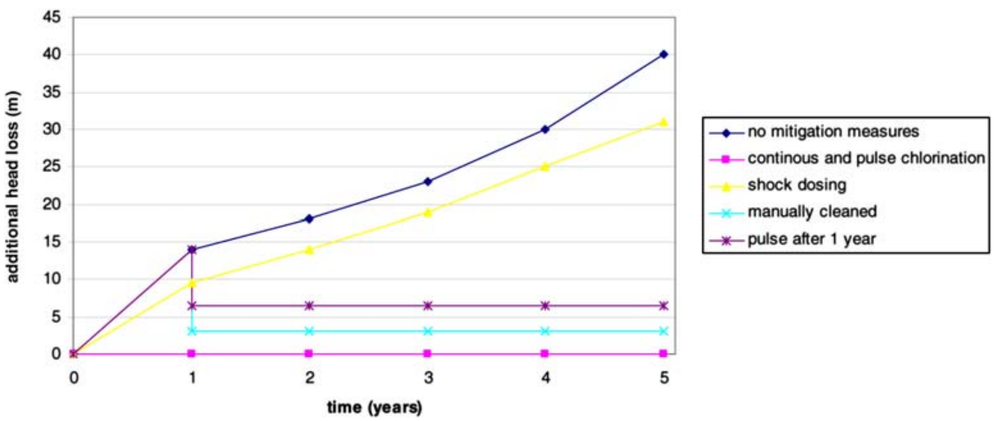

Fig. 5. Case 1—Additional head losses for the different scenarios.

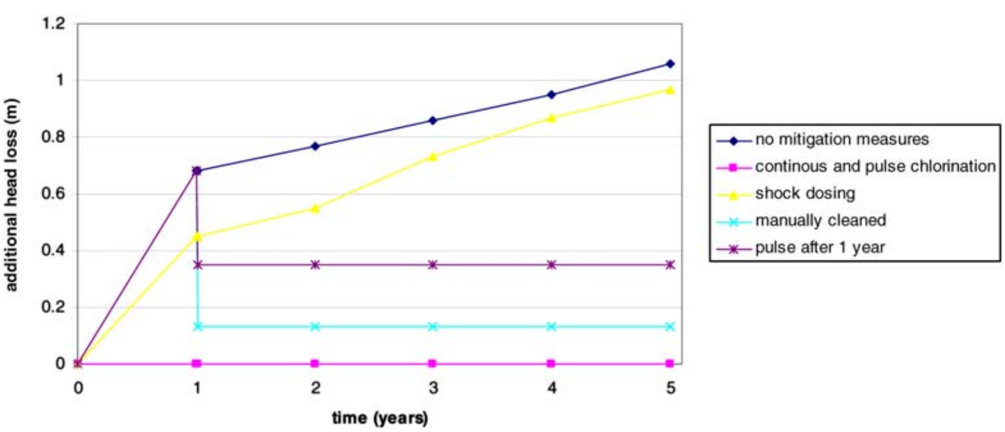

Fig. 6. Case 2—Additional head losses for the different scenarios.

reference case, a system solely affected by wear, with a wall roughness value of 0.1 mm is used.

In Figs. 5 and 6, for each case the additional head loss is shown for the different scenarios. It should be

Table 4
Additional operational costs for the different scenarios

	Case 1		Case 2	
	Maximum extra operational costs (€/year)	MWh/year	Extra operational costs (€/year)	MWh/year
No mitigation measures	970,000	21,500	400,000	9,000
Pulse-chlorination or continuous chlorination	0	0	0	0
Shock dosing	580,000	13,000	280,000	6,000
Manually cleaned after 1 year of operation without dosing	50,000	1,100	30,000	500
Pulse-chlorination or continuous chlorination after 1 year of operation without dosing	120,000	2,700	100,000	2,000

noted that in case of biofouling an average layer thickness and wall roughness are used. A clear difference is observed between the two cases. In case 2, the head loss increase is maximum 1 m, a value which will result in relatively small operational problems due to lower water levels in the pumping station. However, it will still result in significant additional energy losses. For case 1, the additional head losses are significantly larger, in the order of tens of meters. This is much more than the average depth of a pumping station and will therefore cause operational problems like reduced cooling water capacities. In addition, the capacity of the case 1 pumping station is a factor 15 lower.

With respect to mitigation measures, it can be concluded that continuous dosing and Pulse-Chlorination are very effective [4–6] and the effect of shock dosing is almost negligible. For shock dosing, the result is similar compared to no dosing. Manually cleaning is more effective, but also more difficult and costly compared to Pulse-Chlorination or continuous chlorination when implemented after 1 year of operation (without dosing). The effect of biofouling is much larger in case 1 than case 2 due to the higher design flow velocities and a much smaller diameter of the pipeline.

The additional head loss results in additional energy consumption of the pumps and thus additional operational costs. These costs are expressed in Table 4. For all cases, the maximum additional operation costs after 5 years of biofouling are shown.

6. Conclusion

This study shows that biofouling has a significant effect on the operational capacity of a pumping station. The head losses increase significantly, resulting in high additional operation costs. Even more important, due to this increased head loss the design capacity of a pumping station cannot be reached anymore. Both Pulse-Chlorination and continuous chlorination are effective methods to mitigate biofouling. Shock dosing is absolutely not effective and results in the similar problems as compared to no dosing. It has been proven in this study that different mitigation measures taken after 1 year of operation can never result in a clean system anymore. This is because some species are cemented to the surface and some parts of the biofouling species will remain on the surface after mitigation, even after manually cleaning.

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 colonization by fouling. Therefore biofouling control by means of optimal prevention method is the most cost-effective way forward.

The method used for this study has proven to provide additional insight in the impact of biofouling on CWS operation at a specific location. Such methods should be integral part of the design phase of a water inlet to obtain insight how the design can be adjusted in order to prevent high impact on operations. Also, it has been clearly shown that biofouling control should be started already during the commissioning phase, meaning as soon as a water intake system is started up. By doing so, considerable penalties in energy consumption and cleaning efforts are prevented in the best possible, cost-effective way.

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