ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Biofouling of seawater intake grilles - causes and mitigation Strategies

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Manuscript Info

Manuscript History:

Received: 15 July 2015
Final Accepted: 22 August 2015
Published Online: September 2015

Key words:

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Abstract

Gulf seawaters are characterized as warm and tropical. In tropical water there are a large range of marine organisms such as corals, which can and do attach to any surface that is immersed in water. For ships this is a major problem. However this is also a major problem for seawater intakes for desalination and seawater cooling plants in the Gas sector. Also the Oil industry abstracts large quantities of seawater for reservoir injection purposes. The intake has a grille to prevent ingress of large marine animals and divers. These grilles rapidly become blocked by marine growth, requiring frequent cleaning. In this paper we look at the competing technologies for mitigation of this issue as well as look at the unintended consequences, such as increased rates of corrosion often observed downstream.

INTRODUCTION

Biofouling is the phenomena of marine growth on engineered structures which are immersed in the marine environment. It is an entirely natural process which however has caused problems to us ever since we first started building structures large enough for constant immersion. In this paper we will review the current knowledge of the causes and consequences of biofouling and look at the various mitigation strategies which have been developed and highlight the research areas which are needed to address this problem specifically in the gulf region and seawater intake grills in particular. The sheer variety of causative organisms means that even today, after hundreds of years looking at the problem this issue is still a problem and has not entirely been eliminated.

Historical accounts

The first awareness of biofouling begins with the first ships. Once boats became too large to be removed from the water it was only a matter of time before biofouling would render a ship almost inoperable. The growth causes a dramatic increase in the drag and turbulence of the hull as it is driven through the water. As the growth builds up the effective speed through the water decreases significantly and eventually the ship travels with the water (i.e. in the current) rather than through the water. Many of the early trade routes used the ocean currents more than wind directions. The only solution was to periodically haul the ship out of the water to have the hull scraped clean, a difficult and time consuming activity.

The increased roughness of a fouled hull became a source of punishment for ships captains, who regularly used the practice of “keel Hauling”. The condemned man would be tied to a long rope and dragged along the underneath of the ship- the sharp marine growths causing lacerations. Such over-aggressive punishments were required because many of the sailors were kidnapped (press ganging[1] or shanghaiing) and only the threat of such a harsh punishment could keep order on the boat. This was an officially sanctioned form of punishment for many navies around the world[2].

In the late eighteenth and early nineteenth centuries, the practice of covering the bottom of the boat with copper became widespread. It was discovered that copper nails, used in wooden boat manufacture because iron nailed corroded rapidly in the sea, were not affected by biofouling. Copper was (and still is) a relatively rare and expensive metal and so the covering of the ship with copper was a significant investment. However the lack of biofouling ensuing meant the ship could travel much faster and needed less dry dock time[3]. The ship was much more profitable to run, so much so that the term "Copper Bottomed investment" has migrated into the British Language to come to mean a guaranteed return on investment.

Up to the middle of the nineteenth century, all boats, including copper bottomed ones were made of different types of wood. However, the cost of maintaining a wooden boat was extremely high, typically of the order of 50% of the value of the ship per year[4] and so better materials were sought, initially, the iron clad followed by fully iron constructed ships, as the availability increased and cost of iron reduced during the industrial revolution. However, iron hulls are no better than wood at preventing biofouling, and also suffer from extensive and rapid corrosion when placed in seawater. The traditional antifouling approaches, either lead or copper sheeting increased the corrosion rate of the iron via galvanic corrosion, such that failure was often so great as to make the combination untenable[5]. Later workers were able to understand that the success of copper sheeting comes not from the copper itself, but the slow dissolution of copper producing copper (II) ions in the water. It is this constant exfoliation and renewing the surface that provides the antifouling properties. As the metal wears away by friction it is slowly dissolved, washing away any attached organisms with it. This is a mechanical process rather than a toxicological process. When copper dissolves it oxidizes in parallel layers and so very thin sheets of oxide are produced which are then exfoliated. There are many examples of copper bottomed ships lying at anchor for several months to be covered in great thicknesses of fouling organisms[7]. This research was initially carried out by Sir Humphrey Davy[6] and paved the way to more modern approaches to antifouling of submerged sections of ships hulls. A summary of the main progress in antifouling coatings is given in figure 1.

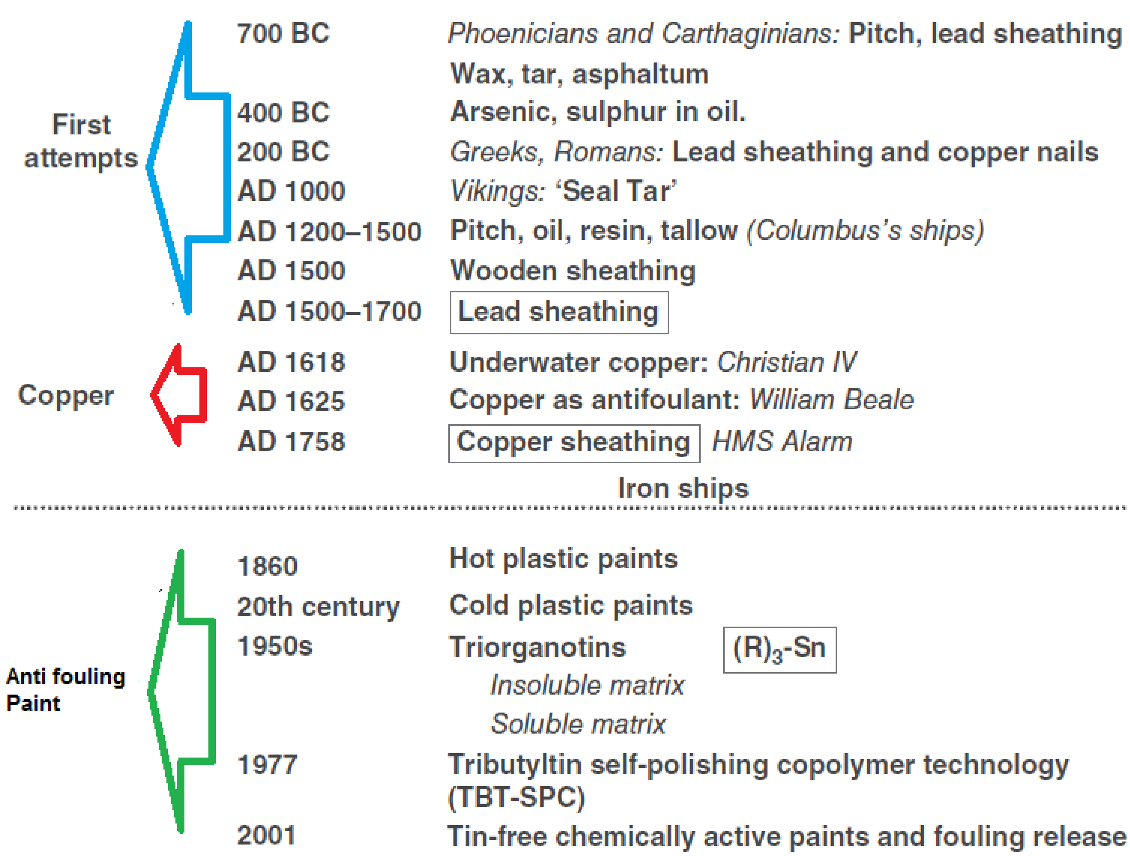

Figure 1 Summary timeline of antifouling technologies.

Types and Causes of Biofouling

Marine biofouling can be defined as the undesirable accumulation of microorganisms, algae and animals on structures submerged in seawater[18].Our main interest lies in the fouling of man-made structures, but biofouling can also affect other marine creatures, commonly the growth of barnacles and tube worms on the shells of crustaceans. In aquaculture, the high concentration of a susceptible species, either fish or shellfish can result in widespread damage by biofouling[19].

Biofouling species can be roughly divided into bacterial and diatomic biofilms (micro-foulers) and macro-foulers (e.g., macroalgae, barnacles, mussels, tubeworms, bryozoans). These differing fouling organisms often work symbiotically as well as antagonistically- the initial colonization species can prepare the surface for later fouling organisms, and then they compete for space. A simplified overview of the fouling process is given in Fig. 2. Whenever a fresh, un-fouled surface is immersed in seawater, regardless of the time of year, every immersed surface will be covered in a matter of seconds by a layer of adsorbed organic compounds (e.g., polysaccharides, lipids and proteins). Within a short time (typically less than a day), after the formation of this 'conditioning layer', the biofouling process starts. Primary colonizers mainly consist of bacteria, yeasts and diatoms, followed by macro foulers such as the macro-algae and macro-foulers such as barnacles.

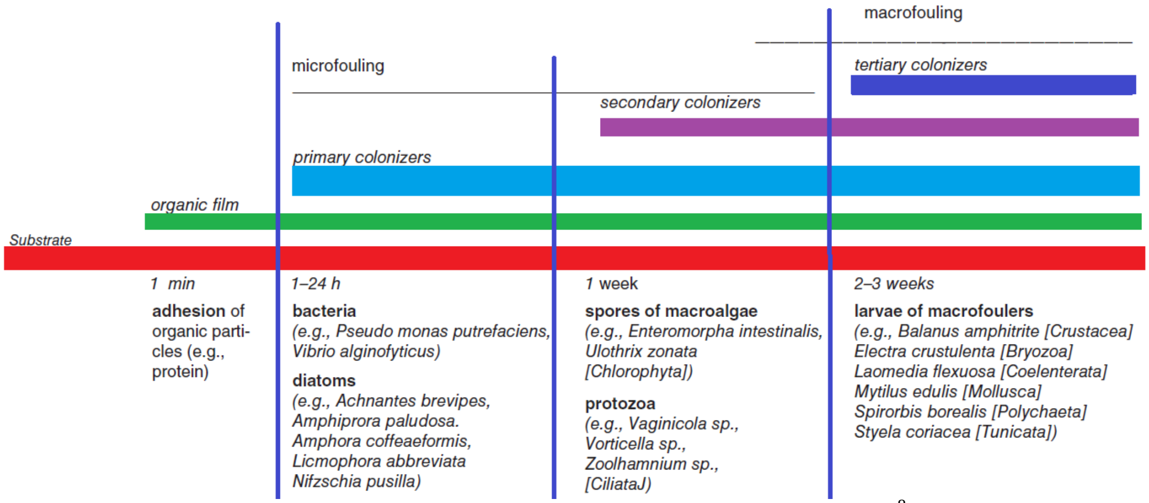

Figure 2: Simplified timeline for the marine biofouling formation process. Source, ref[8]

Typical organisms responsible include the following:

Zebra Mussels (Driessenapolymorpha)

Photo Source: US Fish and Wildlife Service

Many different species of macro algae

Barnacles e.g. balanusamphitrite

The ability of marine organisms to attach and then grow into a biofilm is affected by many parameters. The different types of seawater, such as temperature, nutrient levels, and salinity will determine the geographical distribution of the planktonic organisms. If the organisms are not present it is impossible for them to grow. The time of year can have a large effect as different organisms are released at different times and the seasonal changes may favor the growth of one organism over another. UV intensity and depth will also work to select for different organisms. Occasional toxic releases may preclude some organisms, or localized pollution may prevent biofouling although the author does not advocate an increase in pollution to prevent biofouling! The waters in the Gulf region show less variations in the biofouling communities, due to the relative consistency of water temperature. Even so, fouling in tropical environments is still a very complex and changing phenomenon. Geography pays a major part in the distribution of fouling species.

Costs associated with Biofouling

The vast majority of trade is still conducted by shipping and will continue to do so for the foreseeable future. The movement of goods in ships required fuel and if the ships have biofouling on them they will burn more fuel. The International Maritime Organization (IMO) has calculated that without biofouling technologies, ships will need to use approximately 70% more propulsion power and therefore significantly more fuel. In real terms this translates into a cost difference between no fouling and efficient antifouling, of approximately $150 Billion per year[9]. In one study, the annual economic costs associated with uncontrolled biofouling of US Navy ships was estimated at $56 million[15]. Other studies have shown the large costs associated with biofouling, particularly on shipping[16,17].

Seawater intakes

There are many instances where industry requires seawater in large quantities. In the oil and gas industry, large quantities of seawater are abstracted for cooling purposes, water injection for Enhanced Oil Recovery (EOR)[21] and for fire control (deluge systems)[22]. The gulf region uses very large quantities of seawater for desalination plants. The water intake manifold and pipeline are effectively ships hulls and suffer from biofouling in the same mechanisms as ships hulls. In some ways the situation can be more controlled- for instance, the seawater itself can be chlorinated to prevent marine growth in pipelines, and heat exchangers, a major problem with the use of seawater coolant[20]but in reality the differing situation can lead to different problems. For instance antifouling chemicals cannot be used for water abstraction and many of the copper based antifouling technologies can develop galvanic corrosion in downstream facilities.

Mitigation Strategies

Organotin compounds

As already discussed, the historical development of antifouling technologies has been driven by the needs of maritime transport, with important developments such as the discovery of copper and lead sheeting. The main area of development in recent years has been the improvements in paint technologies which followed the post war boom. After the Second World War, technological development lead to improved paint resins and better paint application technologies, such as airless spraying. At the same time discoveries of highly toxic chemicals such as tri alkyl tin compounds contributed to a major advance in antifouling performance.

Self-polishing or exfoliating paints allowed the toxic organotin compounds to be available at the surface, and thus achieve the anti-fouling required. Unfortunately organotin compounds have been the victim of their own success. They are highly toxic to marine life (that is their purpose) but also remarkably stable in the environment. The damaging effects of tributyltin at Arcachon Bay (France) were first documented in 1980[10]. Since then the amount of marine devastation caused in coastal waters has been very widely reported[23,24]. The damage is so great that many countries have banned all use of tributyltin for small watercraft[25]. This has been imposed because small boats rarely leave estuaries and thus the organotin compounds can accumulate in these waters with devastating effects. Organotin compounds for commercial ships were finally withdrawn from use worldwide in 2008[26,27].

Non tin based approaches

With the loss of tributyltin antifouling there has been very active research to find and evaluate replacement technologies. It has been realized for instance that there may be no need to kill organisms, just make the surface one that the animal would prefer not to attach to. In figure (2) we show that macro-foulers deposit on a preconditioned surface[28]. If we can prevent that surface forming, the macro-fouling will not take place[29]. Additionally, the approach now is to classify coatings by dry dock interval[30].Two grades are commercially available, up to 36 month intervals and up to 60 month intervals.

Current technologies and research can be classified into four main approaches, contact leaching coatings, controlled depletion paints, self-polishing paints, and low surface energy coatings as well as hybrid systems[31].The biocides used in these coatings is usually a mixture of copper (I) oxide and approved organic biocides, typically between 20 – 76% of the dry film mass. The differing technologies are summarized below and graphically in figure 3.

Controlled depletion coatings

The first approach to antifouling paints was rosin based pant binders. This resin allows seawater to diffuse into the paint and allows the antifouling chemicals to diffuse out. These paints control the release by diffusion and the initial diffusion rate is quite high. Eventually the diffusion rate decreases below an effective concentration.

Contact leaching coatings

These systems have a complex matrix of biocide in a dimensionally stable paint matrix. The paint does not normally dissolve and has a constant thickness over time. The biocide leaches out at a relatively constant rate resulting in an increasingly thick depleted layer over time. The diffusion of biocide through the depleted layer decreases over time and this typically limits their application to less than 24 months.

Self-polishing coatings

In these coatings there is no diffusion process. Instead, the anti-fouling chemicals are brought to the surface by virtue of the loss of the paint surface. These paints take their name from the fact that as the surface is layer is lost, the paint smoothens. The life of these paints is directly related to the thickness applied. However, the very nature of the paints does cause some problems, they are very sensitive to mechanical damage and this limits life in practice.

Low surface energy paints

Recent developments in polymer synthesis have seen the creation of highly sophisticated copolymers which are self-segregating. These consist of two components, an epoxy and low surface energy component. Upon application on a steel hull the epoxy is attracted to the metal and the non-polar component "floats" to the surface. The epoxy component then cures to provide dimensional stability whilst the non-polar component provides a surface of exceptionally low surface energy such that no marine organism can attach to it. These paint can be silicone or fluoropolymer. Additional benefits are that the coating can be any colour and that the low friction surface also helps to reduce fuel costs. Disadvantages are that they only work effectively for fast moving ships with little or no stoppage time.

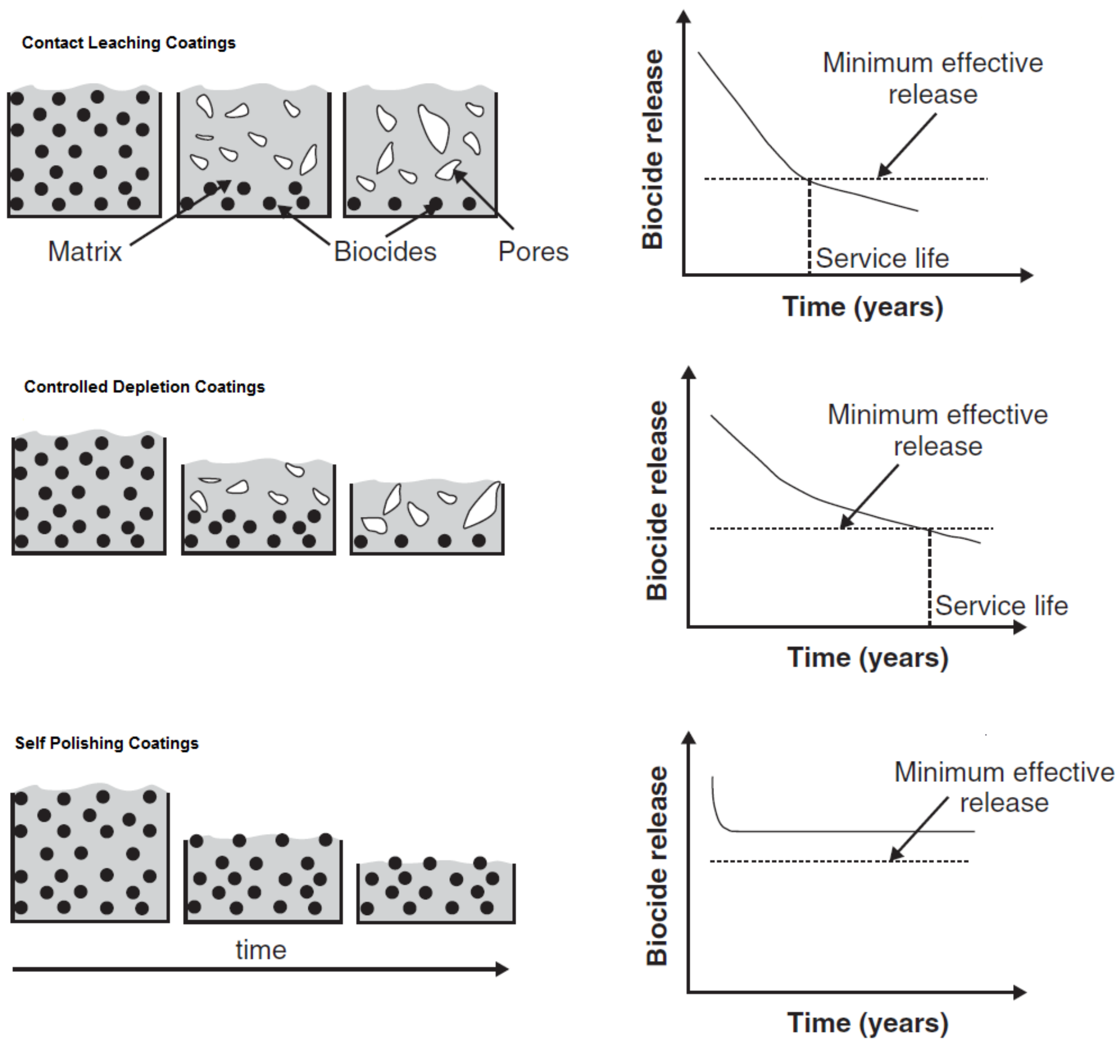

Figure 3 schematic showing how different antifouling paints work.

Alternative Technologies

Chlorination and pigging

In addition to coatings, there are other technologies which have demonstrated success in some situations. For pipelines and contained flows of seawater, chlorination has been employed[11,32]. The dose concentration is important and must be continuously applied. Should the chlorine concentration drop below a critical concentration, biofouling initiation can begin. Bacteria are very successful at resisting chlorination once they have transitioned for the planktonic to sessile. Once established, the colony exudes a polysaccharide biofilm which prevents chlorination diffusion and growth can continue under the biofilm. In this case, periodic scraping to disrupt the biofilm, followed by shock dose chlorination is required. Scraper Pipeline Integrity Gauges (PIGs) (fig 4) designed to fit the pipeline and equipped with wire brushes are frequently deployed[33,34].

Figure 4: A typical example of a cleaner pig

Cathodic Protection

When a metal, such as carbon steel is immersed in seawater it will corrode via the spontaneous formation of anodes and cathodes. Corrosion or oxidation occurs at the anode, and reduction reactions occur at the cathode. If the metal can be connected to an external anode, corrosion of the steel is suppressed. This is the principal of cathodic protection. There are two strategies, sacrificial anode and impressed current. The metal voltage relative to the surrounding seawater is depressed to -850 mV $_{(CSE)}$ to achieve the required protection (fig 5,6). For a fuller study of cathodic protection, the reader is directed elsewhere[12], although there are many sources for information on this subject.

It has been observed that the negative voltage has prevented the biofouling of cathodically protected surfaces, and several patents on the process published[13,14], but in reality have not been commercialized. This is an area which should be investigated thoroughly as the mechanism is poorly understood and yet offers the potential to prevent both corrosion and biofouling[35].

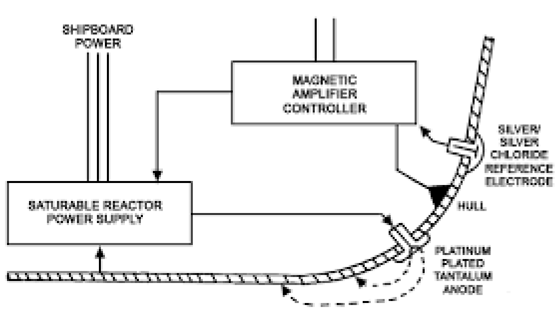

Figure 5 Impressed Current cathodic Protection for ships

Figure 6 Sacrificial anode cathodic protection

Other factors

The flow regime has complex effects. If there is little flow, such as a ship at anchor in a tidal stream, colonization and growth is extremely rapid. In this environment self-polishing paints and low surface energy paints do not perform well as these need flow for activation. If the flow rate is high then self-polishing paints can wear away too rapidly, although it is possible to modify the formulation to suit faster moving vessels. Likewise seasonal variations can have significant effects. The primary colonization species can change with region and season and this can cause changes in growth rates.

Conclusions

The wide range or organisms, the variation in location means that any solution to this problem has to be region specific, this means knowing the distribution of biofouling organisms, both geographically and temporally. The flow regime or turbulence, weather the flow is constant or varied will also affect the final choice. Temperature, salinity and depth all have factors which must also be taken into account. The result of this is that the final solution will be more of a bespoke one than a one size fits all approach. Further work to compare competing technologies in a specific location is desperately needed if we are to provide suitable solutions.

Both of the Authors declare that there is no conflict of interest in the publishing of this paper.

References

1. Rogers, Nicholas. The press gang: naval impressment and its opponents in Georgian Britain. Bloomsbury Publishing, 2007.
2. Runyan, Timothy J. "The Rolls of Oleron and the Admiralty Court in Fourteenth Century England." The American Journal of Legal History (1975): 95-111.
3. Knight, R. J. B. "The Introduction of Copper Sheathing into the Royal Navy, 1779–1786." The Mariner's Mirror 59.3 (1973): 299-309.
4. Young, Charles Frederick T. The fouling and corrosion of iron ships: Their causes and means of prevention, with the mode of application to the existing iron-clads. The London Drawing Association, 1867pp 3-5.
5. Young, Charles Frederick T. The fouling and corrosion of iron ships: Their causes and means of prevention, with the mode of application to the existing iron-clads. The London Drawing Association, 1867pp 37-40
6. Young, Charles Frederick T. The fouling and corrosion of iron ships: Their causes and means of prevention, with the mode of application to the existing iron-clads. The London Drawing Association, 1867pp 56-60
7. Young, Charles Frederick T. The fouling and corrosion of iron ships: Their causes and means of prevention, with the mode of application to the existing iron-clads. The London Drawing Association, 1867
8. Yebra, D.M., Kiil, S., Dam-Johansen, K. (2004). Antifouling Technology – Past, Present and Future Steps towards Efficient and Environmentally Friendly Antifouling Coatings, Progress in Organic Coatings 50, 75–104.
9. http://www.imo.org/MediaCentre/HotTopics/GHG/Documents/ REPORT ASSESSMENT OF IMO MANDATED ENERGY EFFICIENCY MEASURES FOR INTERNATIONAL SHIPPING.pdf
10. Alzieu, Claude, et al. "Evaluation des Risquesdusa l'emploi des Peintures Anti-Salissures Dansales Zones Conchylicoles." Revue des Travaux de l'Institut des Pechesmaritimes" 44.4 (1980): 305-348.

11. Macdonald, I., et al. "Industrial cooling seawater antifouling optimization through the adoption of pulse chlorination." International Cooling Seawater Specialists and Operators Conference Doha, Qatar. 2006.
12. Peabody, Arland Wentworth. Peabody's control of pipeline corrosion. No. Ed. 2. NACE international, 2001.
13. Oliver, Osborn. "Electrolytic method of marine fouling control." U.S. Patent No. 3,661,742. 9 May 1972.
14. Anderson, Edward P. "Cathodic protection and anti-marine fouling electrode system." U.S. Patent No. 3,303,118. 7 Feb. 1967.
15. Schultz, M. P., et al. "Economic impact of biofouling on a naval surface ship. "Biofouling” 27.1 (2011): 87-98.
16. Edyvean, Robert. "Consequences of fouling on shipping."Biofouling”10 (2010): 9781444315462.
17. Fitridge, Isla, et al. "The impact and control of biofouling in marine aquaculture: a review. "Biofouling” 28.7 (2012): 649-669.
18. Murthy, P. Sriyutha, R. Venkatesan, and Keith Cooksey, eds.”Marine and industrial biofouling”. Springer, 2009.
19. Braithwaite, R. A., and L. A. McEvoy. "Marine biofouling on fish farms and its remediation." Advances in marine biology 47 (2004): 215-252.
20. Pugh, S. J., G. F. Hewitt, and H. Müller-Steinhagen. "Fouling during the use of seawater as coolant—The development of a user guide."Heat transfer engineering” 26.1 (2005): 35-43.
21. Alvarado, Vladimir, and Eduardo Manrique. "Enhanced oil recovery: an update review." Energies 3.9 (2010): 1529-1575.
22. Rosliza, R., and WB Wan Nik. "Improvement of corrosion resistance of AA6061 alloy by tapioca starch in seawater." Current Applied Physics 10.1 (2010): 221-229.
23. Drinkwater, J., J. C. McKie, and P. Balls. "Effects of the use of tributyltin antifoulants in mariculture." OCEANS'87. IEEE, 1987.
24. Bryan, Geoffrey W., and Peter E. Gibbs. "Impact of low concentrations of tributyltin (TBT) on marine organisms: a review." Metal ecotoxicology: concepts and applications (1991): 323-361.
25. Matthiessen, P., et al. "Changes in periwinkle (Littorinalittorea) populations following the ban on TBT-based antifoulings on small boats in the United Kingdom." Ecotoxicology and environmental safety 30.2 (1995): 180-194.
26. Dalley, R. "Correspondence: Legislation affecting tributyltin antifoulings." (1989): 363-366.
27. Gipperth, Lena. "The legal design of the international and European Union ban on tributyltin antifouling paint: Direct and indirect effects." Journal of environmental management 90 (2009): S86-S95.
28. Thome, Isabel, et al. "Conditioning of surfaces by macromolecules and its implication for the settlement of zoospores of the green alga Ulva linza."Biofouling 28.5 (2012): 501-510.
29. Yang, Mengyan, et al. "Modelling fouling induction periods." International Journal of Thermal Sciences 51 (2012): 175-183.
30. Chambers, Lily D., et al. "Modern approaches to marine antifouling coatings. "Surface and Coatings Technology 201.6 (2006): 3642-3652.
31. Almeida, Elisabete, Teresa C. Diamantino, and Orlando de Sousa. "Marine paints: the particular case of antifouling paints." Progress in Organic Coatings59.1 (2007): 2-20.
32. 坂口勇. "An overview of the antifouling technologies in power plant cooling water systems." Sessile Organisms 20.1 (2003): 15-19.
33. Baudish, Peter. "Design Considerations for Tunnelled Seawater Intakes. "Intakes and Outfalls for Seawater Reverse-Osmosis Desalination Facilities. Springer International Publishing, 2015. 19-38.
34. De Carellan, Ignacio Garcia, et al. "Methods for detection and cleaning of fouling in pipelines." Emerging Technologies in Non-Destructive Testing V(2012): 231.
35. Little, B. J., and P. A. Wagner. "The interrelationship between marine biofouling, cathodic protection and microbiologically influenced corrosion. "Materials Science Forum. Vol. 192. 1995.