TAHOKAPRESS

Surface Treated Composites
WHITE BOOK

A proven, non-toxic, cost-effective alternative technology for underwater ship hull protection and biofouling control

Boud Van Rompay

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Dedicated to all who care about the future of this planet
and are prepared to contribute actively to its survival.

Contents

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Chapter 1

Introduction

The current system for hull protection and antifouling in general use consists of a combination of zinc primers and epoxy anticorrosion paint coated with layers of copper oxide and other chemicals in a soluble matrix, so that these chemicals can gradually leach into the water with a view to killing fouling organisms when they settle or try to settle on the hull.

This system is designed for frequent reapplication of the chemical layers and for frequent patching and full reapplication of the entire system on bare steel which it requires every ten to fifteen years. It is modeled on the idea of repeated reapplication which means repeat business for the suppliers of the chemicals and the paint, and for the shipyards.

The antifouling coatings in current use have the highly undesirable effect of distributing very large quantities of copper oxide and a number of other biocides, such as the extremely toxic herbicides Irgarol 1051 and Diuron, into the sea, especially around ports, marinas and anchorages. The damage does not end with water pollution; the heavy metals and other chemicals used persist in the sediment, which they contaminate.

The biggest maritime disaster of all time

When an average ship of 50 - 100,000 tons deadweight has a new antifouling coating applied, which is usually every two or three years, some 15 tons of biocides are sprayed onto the hull. Of those 15 tons the large component of harmful VOCs is lost instantly into the air, which is itself highly undesirable. During the application, some of the toxic substances are lost to the air and to the water in the form of overspray and waste. The next step is to refloat the ship. This results in an instant, large-scale distribution of biocides into the water, which pollutes the shipyard and surrounding water and contaminates the sediment locally. The ship then usually sails for two or three years before it goes back to drydock, leaching biocides wherever it goes. Quite often, underwater cleaning is carried out which creates a sudden pulse discharge of biocides into the water where it is cleaned, and eventually into the sediment. This cleaning can take off 30 - 50%

of the remaining biocide coating. Eventually the ship returns to drydock so that the depleted or exhausted biocidal coating can be renewed. The 15 tons of biocide originally applied have all been dispersed, polluting the water and contaminating the sediment wherever the ship has sailed or been laid up or cleaned.

When one multiplies this across the world fleet one sees that it adds up to some 100,000 tons of highly toxic chemicals dispersed into the water every year, with the highest concentrations in ports and harbors, especially around shipyards.

It has been proven that these chemicals persist and that earlier claims about short half-lives were largely exaggerations or fabrications. The chemicals accumulate in sediments and these accumulations continue to build up over the years. Evidently the 100,000 tons that were spread in the year 2000, 2001, 2002 and so on are still there, so the accumulation is amounting to millions of tons.

This distribution of millions of tons of highly toxic chemicals into the water by ships in the form of antifouling paint constitutes the biggest maritime disaster of all time.

Being gradual and continual rather than sudden and temporary, this disaster is not perceived as such and up to now the use of these biocides has not been banned. The full effects of continuing this highly undesirable approach to hull protection and biofouling control will be even more severe than the damage already done.

This environmental damage is a huge price to pay for a system that is not even particularly effective in dealing with biofouling. Using the current antifouling systems, some $70 billion worth of fuel is being wasted every year due to increased hull roughness and biofouling associated with biocidal antifouling coatings.

The soft, leaching type of coating which has to be replaced frequently may serve the purposes of the suppliers in terms of repeat business, but it does not serve the purpose of the end user, the shipping industry or the planet.

A wrong approach

It is a highly destructive approach and cannot be sustained for the following reasons:

1. It results in the annual distribution of tens or hundreds of thousands of tons of heavy metals and highly toxic biocides straight into the water as described above.
2. The chemicals used are not able to keep a slime layer from building up and they are not able to effectively deter macrofouling for the entire period between routine drydocking. They do not function during idle periods of the ship. Thus in-water cleaning is often employed. This results in the sudden depletion of 30 - 50% of the remaining antifouling coating. This causes a

massive discharge into the water where the ship is being cleaned.

3. Due to the nature of the coatings used, the complex build-up of different layers of different substances on a substrate which naturally interacts electrolytically with the metals in the biocide coatings, and the spot blasting, patching and coating repair used to try to extend the life of the coating in drydock, there is a very significant degradation of the coating. It becomes rougher and rougher over its life. Long before the hull is reblasted and a full new coating system applied, the fuel penalty caused by the added roughness, even without considering hull fouling, has been shown to reach 25 - 40%. This means that a great deal more fuel is being burned than necessary to maintain speed. This is accompanied by a proportionate unnecessary emission of CO_2, NOx, SOx and particulate matter. This fact of hull coating degradation is generally ignored or unknown. It is seldom mentioned, despite being a major cause of fuel inefficiency. It becomes suddenly apparent when a 10 - 15 year old hull is blasted to bare steel and a dramatic improvement in fuel efficiency follows when the ship is undocked.

All of the above are the simple, direct consequences of using a coating system for the underwater hulls of ships which is inappropriate, undesirable and unsustainable. The surface preparation, paint and chemical coatings used in these systems are simply substandard. They are not fit for the purpose of protecting a ship's hull throughout its service life and keeping the biofouling to a minimum level where the fuel penalty is acceptable.

There was a point in the development of hull protection systems and biofouling control where a severely wrong turn was taken. Early biofouling control consisted of beaching and careening a ship and scraping the hull. Then the idea of attaching copper sheets to the wooden hull was tried and found to be effective. This system could not be used with steel hulls due to the galvanic action and consequent very rapid corrosion. The idea of using a soft coating with chemicals that leached into the water was tried. It was an attempt to replace elbow grease with poisonous chemicals. The ultimate toxic substance was TBT. The harm to the environment was so great that this was eventually banned after great damage was done which is still being felt today. However the fundamentally flawed idea of leaching heavy metals and poisonous substances continued and copper oxides and a number of herbicides and other chemicals were used instead.

Note that nailing copper sheets to the wooden hull of a sailing ship is very, very different from coating the steel hulls of thousands of ships with many tons of chemicals designed to leach into the water. These cannot even be compared. The only connection between the two is that the sheets were of copper and the most common biocide used is copper oxide. But the comparison ends right there.

The basic proposition

The proposition is quite a simple one. Transport by sea is economical, efficient and very useful. It has been so for thousands of years. The sea, however, is a much tougher, harsher, more aggressive environment for man-made objects, including ships, than anything experienced on dry land. Water, especially saltwater, is highly corrosive. There is galvanic, electrolytic corrosion of the mild steel which is the most common material for ships' hulls. There are the forces of cavitation which accompany fluid flows and can be very damaging to steel and other substrates. There are particles in the water such as ice, sand, gravel or lava which are all aggressive to the underwater hull. Impact of objects is another source of attack. Last but definitely not least there is the attack of marine growth, plants and animals which attach themselves to the hull with, in some cases such as barnacles, amazing tenacity. All these factors pose a challenge to shipping. The hull must be maintained in good shape, smooth and free of fouling in order for the ship to travel rapidly through the water with an efficient consumption of fuel.

The whole idea is to continue transport by sea, keeping ships' hulls protected and smooth, while creating a minimal and sustainable effect on the environment. The environment here refers to water quality, sediment contamination and the air or atmosphere. Shipping can have an adverse effect on all of these. The idea is to keep this effect to a minimum.

The approach taken to accomplish this has been completely wrongheaded. The use of a soft, toxic coating which does not protect the hull well, which becomes rougher and rougher over time, does not prevent slime and algae from attaching to the ship's hull nor invasive species from colonizing niche areas, which distributes hundreds of thousands of tons of heavy metals and highly toxic chemicals into the water every year and which needs frequent replacement, is not suitable and does not serve the purposes of transport by sea, no matter how profitable this approach may be to suppliers in terms of repeat business.

A fully workable, tested, successful, economically viable alternative

Over the last 15 years we have researched, formulated and put into effect an entirely different approach, much closer to the original concepts of maintaining smooth and clean hulls using elbow grease rather than biocides, but also brought into line with modern technology appropriate to the 21st century.

Research led in a 180° opposite direction, away from the soft, biocide-leaching coating. This alternative approach consists of a hard, tough, resilient coating which thoroughly protects the hull, whether steel, aluminum or glass reinforced plastic (GRP), for the service life of the ship. It is the exact opposite of the repeated recoatings model. It is the exact opposite of the soft, leaching type of coating, being hard and inert with no active ingredient emitted into the water. Consisting mainly of glass flakes in a resin, it is an electrical insulator. It has been shown to entirely prevent cavitation damage on 100% of rudders coated with it, and rudders are notorious for succumbing to the forces of cavitation.

The coating protects the hull and underwater parts of the ship because it is hard, tenacious, tough, resistive and resilient. Instead of degrading over time, this coating becomes smoother and more efficient hydrodynamically as a result of routine in-water cleaning.

The coating is kept clean of fouling *by cleaning it*! Nothing could be more simple or obvious. If you want something to be clean, you clean it. And "killing is not cleaning," to quote Professor Hans-Curt Flemming of the university of Duisburg, Essen. The cleaning is done with the vessel afloat and is accomplished without harm to the coating or to the environment. It can be repeated as often as needed, depending on a ship's sailing pattern, climate and other factors, in such a way that the hull never becomes fouled beyond a light slime. But even heavy calcareous fouling can be removed without the coating suffering any damage.

This system has the significant added benefits of reducing fuel consumption and thereby GHG, and of eliminating the spread of invasive aquatic species. Compared to other coatings it has very low VOC emissions. Because it is applied only once, it eliminates the environmental and economic liabilities associated with repeatedly removing and reapplying the bottom paint and chemical layers.

As demand increases and this alternative approach gains acceptance, the facilities and infrastructure required for rapid, high quality industrial level hull cleaning will be established universally. The idea of a ship wash will prevail. It will not be along the lines of a car wash because the different hull shapes and sizes and the differences between activities on land and activities in the water preclude this. Nevertheless, the cleaning can be performed thoroughly, completely, rapidly and efficiently with minimal interference to a ship's operating schedule. The cost of such cleaning is still much less than the money currently wasted on fuel through hull roughness and fouling and on the repeated reapplication of the coating systems currently in general use.

This then is a coating system which is fit for purpose, is economically viable and environmentally sustainable.

The only loss associated with this system is the loss of repeat business to bottom paint and chemicals suppliers who rely on frequent coating replacement as their business model. This system is what shipping, shippers and the planet need.

Accountability

There is a point which is often misinterpreted, ignored or missed. When a shipowner decides to coat his ship, whether new or in service for some time, with toxic antifouling paint, he is taking a clearcut decision to continue to pollute the sea by just that amount of biocides. If he orders a ship to be coated with 15 tons of biocides, he knows that those 15 tons are going to add to an accumulation of marine pollution. Whether or not this is technically legal is not the issue. TBT was technically legal for decades before it was finally banned, but this did not reduce the harmful effects of its use. Nor did it exonerate those who continued to use it despite the fact that its harmful effects were well known and publicized broadly. It is those individuals who decided to use or continue to use TBT on their ships who are accountable for the consequences. They too hid behind the fact of legality to continue to wreak environmental havoc.

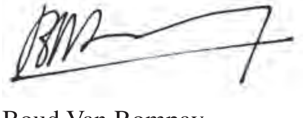
The same applies to the current crop of biocides. There are innumerable papers pointing out the dangers to the environment of copper oxides and all the various biocides currently in use. These are known facts available to all who choose coatings for ships and boats.

Therefore those who continue to use such systems in the full knowledge that they are contributing to a maritime disaster of this magnitude are fully accountable for that contribution and that disaster.

The fact that a fully tested, successful and better system for protesting ships' hulls and dealing with fouling is available, adds to that accountability.

That the alternative happens to be cheaper in the long run and will save shipowners and operators much expense in terms of fuel wasted, additional drydocking fees and the cost of reapplication, renders it inexcusable to continue to use the toxic solution.

This book examines all the factors involved with ample references to back up the statements made and conclusions reached.



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Antwerp, October 2012

Chapter 2

Current Practices

It is easy to simply continue using the conventional methods for the protection of ships' hulls and the control of biofouling which currently prevail broadly. But are these methods the best available, and are they sustainable?

Chapter overview

Despite serious concerns about atmospheric emissions, about marine pollution and sediment contamination, about the spread of invasive aquatic species, despite an industry slump, idle shipping, the high cost of fuel and general economic difficulties, the shipping industry as a whole tends to be fixed in its ways and show little enthusiasm for change of technology or practices – at least when it comes to underwater hull protection and biofouling control.

While every aspect of ship hull protection and fouling control will be covered in detail in this book, this chapter is a survey and overview of current practices, technology and methods in broad, general use at this time: coating systems, ship bottom maintenance in dry-dock and under water, hull-borne invasive species prevention, propeller maintenance, rudder protection and other related issues and concerns.

By comparing these general current practices with an ideal and with best available practices which will be described in later chapters, it is possible to make informed decisions to bring about needed and desirable changes.

There is no overall, authoritative tabulated pool of facts and figures with regard to these various practices and methods, so some of the information in the chapter is, out of necessity, an estimate based on what accurate information is available.

It is clearly understood that this is a general, average description of current practices in broad use and that there are many exceptions to the customs, usages and practices which are described herein.

Types of hull coating in general use

There are really only three mainstream categories of hull coating systems available and in use today. While these are compared in much greater detail in Chapter 7, a brief summary is given here.

Antifouling (AF)

The antifouling system in general use consists of an anticorrosive paint system, usually a zinc primer and several layers of epoxy, covered by a top coat or top coats which leach copper oxides and a number of other biocides into the water in order to kill off fouling that attaches or tries to attach to the ship bottom. These paints gradually release the toxic substances into the water over a period of a few years, after which time they become depleted and need to be replaced. They operate on the same principles as did the now banned TBT-based coatings, but use other biocides than compounds of tin as the active ingredients. This type of coating is sold by all the major marine hull coating manufacturing companies, with variations in the combination of biocides used and the methods by which these are leached into the water. They generally go under the heading of "antifouling paint," "antifoulings," "antifoulants" or simply AF.

There are three main types of AF paints.

1. Contact leaching paints

This is the simplest and oldest biocidal antifouling. A binder is combined with as much biocide as possible, and the contact of the seawater dissolves the biocide so it is leached into the water. The binder is usually a vinyl or acrylic copolymer and the biocide is usually cuprous oxide. Because the binder is not soluble in water, a leached layer builds up which prevents further release of the biocide, giving this type of coating a very short life.

These are cheap, low-end antifouling paints, don't last more than about a year and are not commercially important these days.

2. Controlled depletion polymers (CDP) and soluble matrix or ablative paints

This category includes soluble matrix paints, also referred to as ablative antifoulings. The more modern versions are known as controlled depletion polymers (CDP) to differentiate them from the next category, self-polishing copolymers (SPC). In many cases these terms, CDP and SPC have become marketing terms rather than technical descriptions and the boundaries between them are blurred.

Part of the binder in a CDP is soluble in seawater so that deeper layers are exposed. The paint coating gets thinner and thinner over time as the biocide is leached into the water and the binder dissolves.

The soluble binder used is usually rosin which has a relatively low mechanical strength. The CDP tries to reach a compromise between being soluble enough to attain a sufficient level of leaching, and being strong enough to resist abrasion and damage.

This type of paint is still liable to the formation of a leached layer which then prevents biocides from escaping, rendering the coating ineffective after time and limiting the effectiveness of these coatings to about three years maximum.

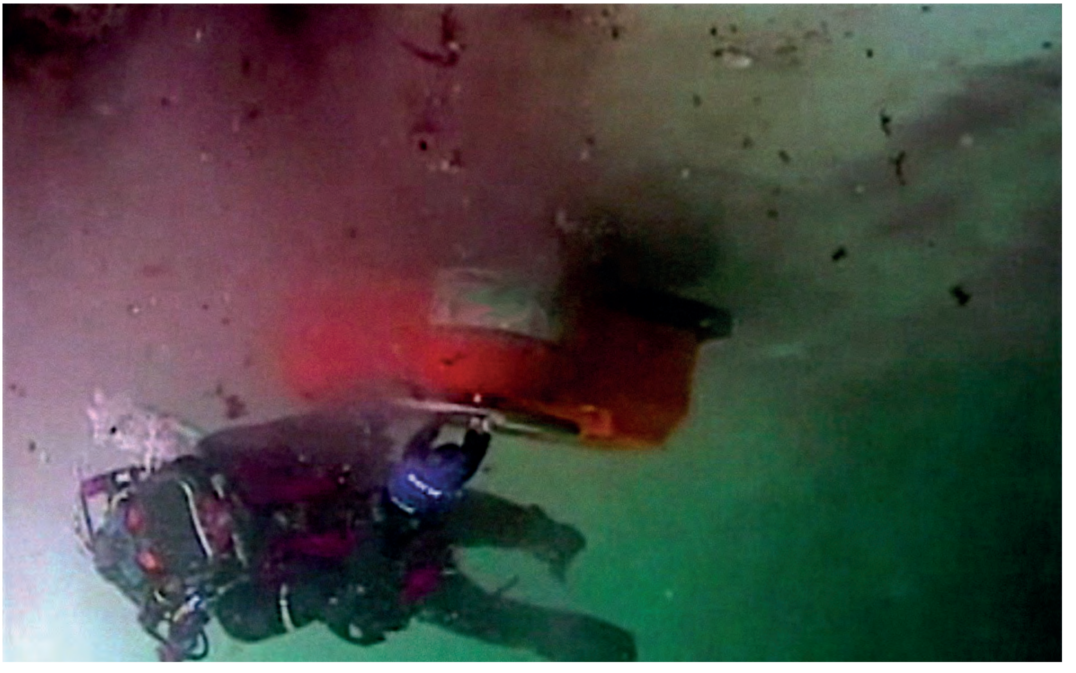
3. TBT-free self-polishing copolymer (SPC)

The banning of TBT led to the development of tin-free self-polishing copolymers (SPCs). The chemistry of these coatings is not important for the purposes of this book. There are different variations and different biocides but the principle is that poisonous substances are released into the water to kill potential biofouling. The different binders developed are mainly an attempt to extend the useful life of the coating. The basic principle of a biocide-leaching coating remains the same for all biocidal coatings.

There is a chemical reaction between the seawater and the biocides on or near the surface of the paint so that the biocides are released into the water. The surface layer of biocides gradually leaches into the water, allowing the water to react with the next "layer" of biocides which are then released. The leached layers are very thin and can be washed away by the progress of the ship through the water (this is the "self-polishing" aspect - the paint surface which is fairly rough to begin with becomes smoother as the biocide leaches out and the coating wears down), and the process can continue for some time, limited by the initial thickness of the antifouling layers. These paints leach heavy amounts of biocides continually and the "self-polishing" name simply refers to the fact that the coating wears away steadily.

Because the leached layer requires a current of water to wash it away so that the next layer can be exposed, these biocidal paints are not effective for vessels which spend some time laid up. It is also not as effective in the niche areas of the ship which are, by definition, protected from the normal flow of water past the main hull. This is true of all the AF coatings where a leached layer builds up and remains in place, blocking the escape of more of the biocides. When cleaned in the water these coatings emit a pulse discharge of biocides which can amount to 30 - 50% of the remaining biocidal layers.

Again, SPC has become a marketing term more than a technical one, referring to the high end of antifouling paints with a longer life and a higher price sticker.



Underwater cleaning of a copper-based biocidal paint.

Hybrid AF paints

There is a class of antifouling paints which falls somewhere between the high-end SPC and the lower-end CDP which is basically an SPC with more rosin in it, making it more soluble. It ranks between CDPs and SPCs in price and in useful lifespan. These are known as hybrid antifouling paints.

The biocides in general use

Since the AF coatings rely entirely on biocides for their effect, it is worth briefly examining the biocides which have been in general use since the ban on TBT.

Copper

The main biocide in current use in AF paints is copper or some derivative of copper.

While copper as a trace element in tiny quantities is needed by humans and life forms, it can be highly toxic when in concentration, with a number of health hazards for humans and aquatic life. It is persistent, and the only way to get rid of it in ports and harbors is by dredging which is an extremely cumbersome, onerous and difficult operation which in itself is liable to create further environmental hazards.

The evidence available on the effects of copper has already led to a number of laws and regulations forbidding its use in AF paints in certain areas and on certain types of vessels, and also banning the underwater cleaning of ships coated with copper-based AF paints in many ports and harbors.[1]

Copper and copper derivatives are the most common biocides in use, but they are not the only ones.

Zinc

Another less-used metallic biocide used in AF paints is zinc and zinc-derived compounds. Tests have shown that both copper and zinc are toxic to non-target organisms and that the levels of zinc as well as those of copper need to be considered when evaluating the potential impacts of antifouling paints.[2]

"Booster" biocides

Because the copper- and zinc-based antifouling coatings are not as effective as the banned TBT-based coatings they replaced, paint manufacturers have added other biocides into their antifouling coatings in an attempt to make them effective against a broader variety of aquatic species. These include a number of pesticides, herbicides and fungicides, some of them used in land-based agriculture. These are often referred to as "booster" biocides but this is a misnomer and a euphemism. They are additional biocides in their own right, some of them considered harmful enough to be banned in some areas. They are more accurately referred to as co-biocides.

Diuron is used as a "booster" biocide in AF hull coatings. It has been entirely banned as an active ingredient in antifouling paints in the UK but is still in use in other parts of the world.

Irgarol 1051, chlorothalomil and Sea-nine 211 (DCOIT) are also in use in AF coatings though they have been banned from use on boats under 25m in length in the UK.

Irgarol 1051 is a herbicide and was the first of the "booster" biocides to become prominent as an environmental contaminant. Concentrations of the herbicide have been found in ports and marinas around the world and also in fresh water. It is considered to be non-biodegradable.

Sea-nine 211, which is a chemical known as DCOIT, widely used as an additional biocide in AF coatings, has been found to be toxic to non-target species (in other words, species which do not attach to ship hulls as biofouling) and its continued use is discouraged.

Zinc pyrithione, another biocide in use in AF coatings, has been found to be more toxic than Irgarol and Sea-nine 211.

To quote one review article from 2003, from which much of the above information has been extracted, “Worldwide occurrence and effects of antifouling paint booster biocides in the aquatic environment: a review,” by I. K. Konstantinou and T. A. Albanis:

> **Continuous monitoring of biocides concentration profiles in water, sediment and biota is needed to support information that should lead to concerted action to ban or regulate the use of booster biocides. Data are available for the biocides most commonly used in Europe, North America and Japan (Irgarol 1051, Diuron, Sea-nine 211) whilst few or no data are available for other biocides.**
>
> **…**
>
> **The need for further research in several vitally important areas such as occurrence, fate and effects of booster biocides is well established by the scientific community, in order to underpin risk assessments and protect environments close to moored vessels. Although the concentration levels of some biocides were not high enough to have acute toxic effects directly on higher species, their chronic effects at low concentrations are unknown and difficult to determine. Gaps in the available data make difficult the evaluation of their impact on the aquatic environment. The precautionary principle should be invoked with respect to the use of booster biocides and provides a good basis on which to formulate policies to the marine environment.**[3]

There is a tremendous amount of literature and debate about the environmental effects of copper and co-biocides used in antifouling paint but overall there is abundant evidence to indicate that these biocides are highly toxic to the marine environment and the food chain, that they represent a danger to humans and that the extent of that danger has not been fully assessed. Similar debate surrounded the use of TBT which prolonged its use for years after it was known to be severely toxic and hazardous, the destructive results of which prolongation continue to this day, long after the biocide was banned.

The environmental concerns surrounding the use of biocides in antifouling paint will be covered in more detail in Chapter 5.

Antifouling coatings are perceived as being cheaper than either fouling release coatings or the better hard coatings. Since they are intended to last only three to five years before replacement, surface preparation is often less thorough than it would be for a hull coating intended to last the life of the ship. In working out the cost, however, it is important to take into account the total ownership cost for the life of the ship, including the cost of application and reapplication, time in dry-dock, off-hire time and above all the fuel penalty involved which is the biggest single expense, as well as the long-term cost to the environment which is seldom accounted for.

Fouling release (FR)

Another category of hull coating systems which has increased in popularity is a “non-stick” type of coating which works on the principle that it is difficult for fouling to stick to it in the first place and easy for it to fall off, wash off or “release” when the vessel is under way, especially at speed. Most of the coatings currently available in this category are silicone-based. They do not work on the principle of leaching biocides, and are advertised as being non-toxic and working mechanically rather than chemically. While there are a variety of different coatings in this category and not all are silicone-based, they all come under the label of “fouling release coatings” or FR (sometimes FRC).

The theory of how these surfaces work is not complicated. Since the term “low surface energy” is often used to describe how fouling release coatings work, it is worth explaining the term briefly here.

Two main types of solid surfaces can interact with liquids. Traditionally, solid surfaces have been divided into high energy solids and low energy types. Solids such as metals, glasses and ceramics, due to their chemical composition, have surfaces which require a large input of energy to break, so they are classified as “high energy.” The other type of solids are held together by weak forces and therefore require a low input of energy to break them, and so are referred to as “low energy.” Silicones and fluoropolymers fall into this second category (fluoropolymers are organic polymers such as Teflon® which are polymers that contain fluorine; a polymer is a substance defined by its particular chemical structure which forms a variety of synthetic organic materials such as plastics and resins).

This is what is meant by “low surface energy.” The two types of surface behave differently towards liquids, including adhesives. The low surface energy type are harder to wet and harder for adhesives to stick to. Fouling species stick to the ship hull using glues that they exude. A low energy surface is harder for them to stick to than a high energy surface.

This is an oversimplified explanation of how FR coatings are said to work but even the complicated explanations involving fracture mechanics do not fully explain the mechanism. Thickness of the coating plays a part as well, and to be effective an FR coating has to be relatively thick. Otherwise the adhering barnacles, for example, cut through to the substrate and the surface fails.

Silicone oils leached by the most commonly used silicone, poly-dimethyl-siloxane (PDMS), are part of the puzzle. Fluoropolymer oils are also leached into the water to increase the effectiveness of some fouling release coating systems.

These coatings are not supposed to work on the basis of leaching biocides as do AF coatings. As such they have been labelled "non-toxic," "environmentally safe" and "green." However, there is more to the picture than this. Some FR coatings such as those containing PDMS do leach silicone oils and these oils, undissolved, can cause physical-mechanical effects with trapping and suffocation of marine organisms;[4] some have other ingredients or catalysts which are toxic, in some cases as toxic as TBT.

A recent study shows that some of the silicone FR coatings emit molecules which interfere with the biochemistry of the attaching animal and alter the enzyme activity of the glue exuded.[5] A more recent study concluded that leachings from commercial fouling release coatings can retard the development of sea urchin and fish hatchlings and that these effects required further study.[6] This is no longer merely a "low surface energy" manifestation (where water droplets might be seen to run off a low energy silicone or Teflon surface but thoroughly wet a high energy surface glass windscreen for example).

Silicones are very often catalyzed using dibutyltin dilaurate (DBTDL), a cheap catalyst which is as toxic as TBT. When DBTDL is used as a catalyst in silicones, one gram of the final silicone coating contains 215 micrograms of DBTDL. A release of four micrograms per square centimeter of coating per day is deadly to settling marine life. This is toxicity.

What effects this may have on marine life generally should be carefully explored before labeling the products as non-toxic. Many are not. In fact, these coatings and the chemicals they do leach should be evaluated to see whether or not they fall under the EU Biocidal Products Directive (BPD) and if so they should be classed as biocides and treated accordingly.

Fouling release coating systems usually consist of multiple layers including an epoxy corrosion protection scheme (usually a primer and one or more coats of epoxy), a tie coat to facilitate the adhesion of the fouling release coating to the epoxy where needed, followed by the fouling release top coats (silicone or fluoropolymer).

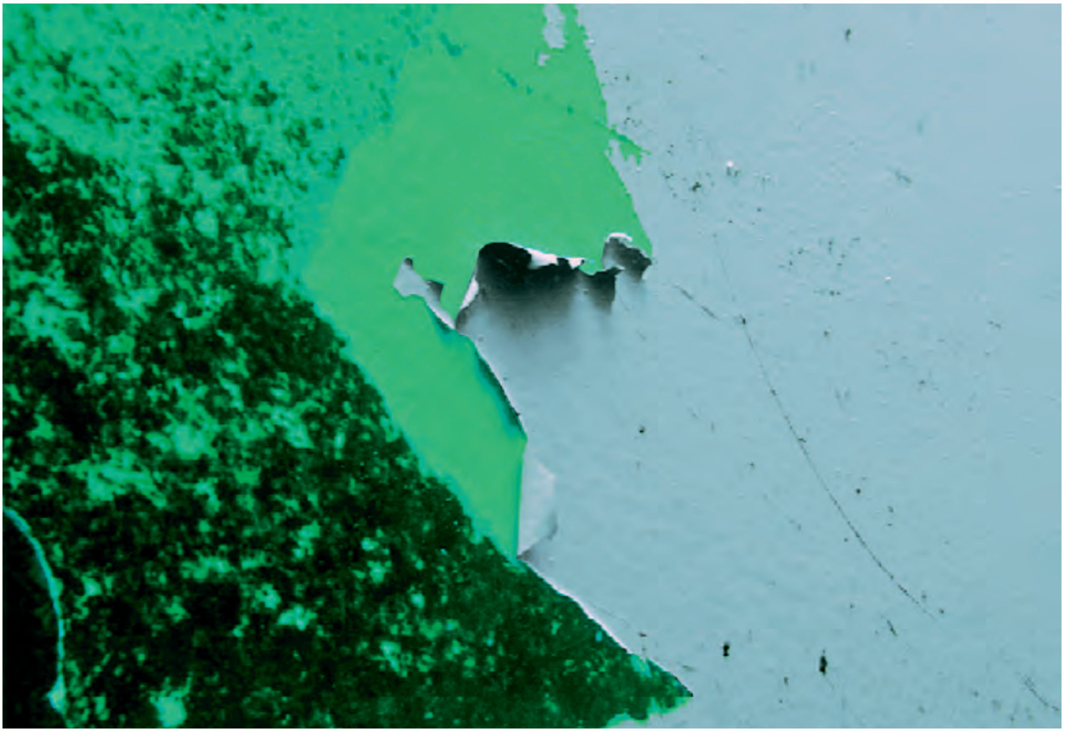
There are two main classes of fouling release coating systems:

1. Silicone (the most prevalent)
2. Fluoropolymers.

In general, silicone coatings are hydrodynamically smoother than AF coatings. If kept clean, even of medium to heavy slime, considerable fuel savings over AF coatings can be attained. This can, if properly managed, outweigh the extra cost of the silicone coating system. They tend to be more expensive than FR coatings.

These coatings tend to foul up if the ship is quayside or at anchor for any length of time. If barnacles are permitted to attach and grow on the silicone surface, they can cut through the silicone to the underlying epoxy coats or primer or even the metal hull, depending on the film thickness of the FR top coat and the underlying coatings. If this is extensive then the coating will be damaged. Repair is difficult and the answer may be reapplication of the silicone FR system.

FR coatings, as is the case with all current hull coatings, accumulate slime when the vessel is stationary. Some of this slime may be washed off silicone FR coatings if the vessel travels at speed, but enough is left behind to create a significant fuel penalty as covered in detail in Chapter 4.



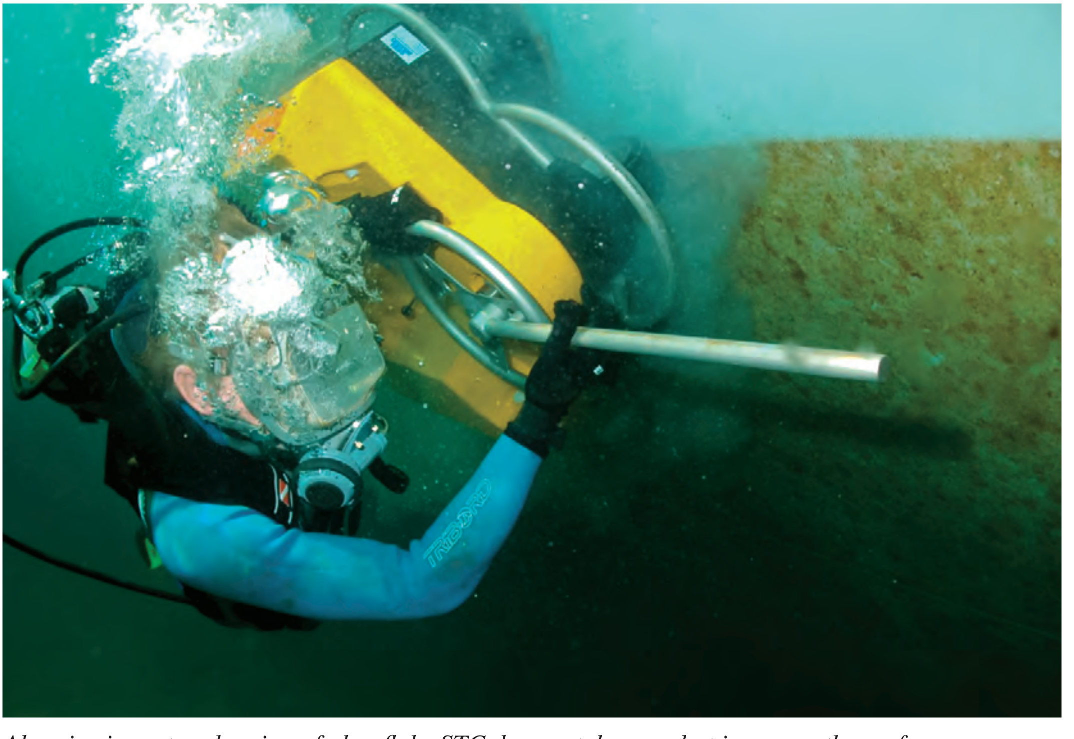
A partially cleaned silicone fouling release showing damage and fouling.

This, and the fact that any abrasive cleaning of silicone FR coatings damages the coating, has led to research into what has been termed "hull grooming:" frequent, light cleaning of the hull using unmanned, low pressure cleaning machines designed to remove fouling while it is still very light without damaging the coating, still in experimental stages at this time. Silicone coatings can be cleaned successfully using low pressure water cleaners in dry-dock, and the fouling, if light, comes off easily.

While FR coatings appear in general to be more expensive than AF coatings, this must be weighed against the fuel savings that result from a hydrodynamically smoother hull and the lowered impact on the marine environment compared to AF systems. This advantage is lost if the hull is allowed to foul and not cleaned before the fouling gets heavy.

Hard, inert coatings

A third general category of hull coating systems can be grouped together under the heading of hard, inert, non-toxic coatings. There are a number of subcategories here. They are generally either epoxies, polyesters or vinylesters; some are reinforced with glass flakes. Variations include ceramic-epoxy. Some come under the heading of *surface treated composites* (STC) since they can be conditioned under water with special equipment and their surface improves with routine cleaning. In general these coatings are designed to protect the hull against corrosion and are intended to be used in conjunction with routine cleaning, either using high pressure washing in drydock, or underwater cleaning with the vessel still afloat. Routine and timely cleaning keeps the fouling to a minimum and the hull operating at optimum performance. These coatings are non-toxic and do not leach or emit harmful chemicals into the water. A number of different coatings in this category are manufactured by various companies.



Abrasive in-water cleaning of glassflake STC does not damage but improves the surface.

What these coatings have in common is that they are inert, non-biocidal and non-toxic. They will foul. In order for them to be useful as ship hull coatings they must either be used in waters where marine fouling is not a problem (e.g. ice) or they must be cleaned routinely to keep the hull free of biofouling. Because the coatings are hard, some of them can be cleaned vigorously in the water using abrasive brushes without being damaged and without the pulse release of biocides which accompanies the in-water cleaning of AF paints, or the damage which can occur when FR coatings are cleaned aggressively.

Hard coatings do not ablate or gradually dissolve as do AF paints. Nor do they leach oils or molecules of their substance as with the FR coatings. They are inert and do not work on the principle of leaching chemicals into the water. From an environmental standpoint they are the safest and least harmful of the coatings currently in use.

The best coatings are extremely tough and hard but also flexible. Some hard coatings are too brittle to survive long, as the ship's hull can flex considerably and the coating needs to flex with it in order to remain firmly attached.

For the purposes of antifouling, hard coatings cannot be considered on their own but only in combination with a workable, economically viable and environmentally safe strategy for cleaning. The expense and inconvenience of frequent drydocking precludes that option, leaving as viable only the various methods of cleaning the hull while the vessel is afloat.

There is a glassflake reinforced coating which is guaranteed for 10 - 12 years and expected to last the lifetime of the ship, needing no more than minor touch-ups in dry-dock if damaged. This type of coating, combined with routine cleaning, can produce enormous savings in fuel and reapplication costs, which significantly outweigh the cost of initial preparation and coating and of the subsequent routine in-water cleaning.

The main subcategories of hard coating include:

1. Epoxy
2. Glassflake reinforced epoxy or polyester
3. Glassflake reinforced vinylester resin, also known as surface treated composite (STC)
4. Ceramic-epoxy (used on boats and recreational craft at present).

Although these coatings are all included in the category of hard coatings there are considerable differences among them.

1. Epoxy

Epoxy coatings are in widespread use as anti-corrosion protection in both the AF and the FR systems. At least two coats of the biocidal AF paint are usually applied over a primer and two coats of epoxy. The copper in the AF paint must not come in contact with the steel of the hull;

otherwise rapid corrosion occurs. Similarly, FR coatings are usually applied over an anticorrosion scheme consisting of an epoxy primer and a second coat of epoxy.

Epoxy coatings are also used on recreation craft. But a pure epoxy coating does not work very well on a ship hull. It tends to be brittle which means that when the hull flexes the epoxy is liable to disbonding – the adhesion is broken. It is also not even as hydrodynamically smooth as a typical AF coating.[8] It is perhaps to overcome these shortcomings that epoxy-ceramic and glassflake reinforcement of epoxy and other hard coatings were developed.

A special case of epoxy coatings are those designed for ice-going vessels and icebreakers. These are abrasive resistant coatings with low ice adhesion. They require special hot application, making them relatively difficult to apply since they "go off" quickly and will not cure at lower temperatures. Epoxy coatings damaged by ice can lead to very rough hulls with consequent high increases in fuel consumption. Experience has shown that a glassflake STC makes a better, tougher, more durable coating for ice-going vessels or icebreakers. It is also much easier to apply in adverse conditions.[9]

2. Glassflake reinforced epoxy or polyester

These coatings are stronger, more flexible and more long-lasting than the pure epoxy coatings. They can be cleaned underwater without releasing chemicals into the marine environment. The glass flakes enable them to achieve a smoother finish than with pure epoxy coatings and they are tougher.

Their life expectancy is, however, considerably shorter than that of the next category, glassflake vinylester resin surface treated composite.

3. Glassflake vinylester resin surface treated composite (STC)

Glass reinforced vinylester resin coatings have long been used as tank liners. Their use as ship hull coatings is more recent, postponed perhaps by the higher cost of materials. This is another inert coating which has been tested for toxicity from use or underwater cleaning and found to have no toxic emission.[10]

A special formulation of glassflake vinylester resin has been used successfully as a ship hull coating for over ten years. In combination with routine in-water cleaning, this has acquired the term *surface treated composite* (STC), and has proved very effective in terms of non-toxic hull protection and a system which can achieve great fuel savings when correctly applied and maintained.

The glassflake STC is easy to clean underwater without damage to the coating or hazard to the environment. The frequency of the cleaning required varies with the sailing pattern of the vessel and the temperature of the water where the ship is operating, but each cleaning results in a smoother hull.

The glassflake STC is usually applied once in two coats (although this can be increased to three or even four coats under special circumstances), requiring no primer. Time in between coats can be as short as three hours, depending on conditions, and there is no maximum time for overcoating. The resulting homogeneous coat is thick (minimum 1000 microns), very tough and abrasive resistant, and lasts the lifetime of the ship, requiring only minor touch-ups (typically less than 1% of the coated area) during normal scheduled drydocking if any sections are mechanically damaged.

Another unusual property of the glassflake STC is that, unlike all other coatings which deteriorate when cleaned underwater, the STC becomes smoother over time without any significant loss of thickness. It thus becomes more hydrodynamically smooth and less prone to fouling with time and routine cleaning.

Even thick, hard fouling can be completely removed from an STC-coated hull leaving no trace of damage from the fouling or the cleaning.

The glassflake STC puts an end to the need for drydocking a ship in order to paint. Any minor touch-ups required can be carried out when the ship is in dry-dock for usual class inspection, maintenance or repairs without significantly extending the time in dry-dock.

This STC is somewhat more expensive than the glassflake reinforced epoxy or polyester coatings but this is more than made up for by its much longer service life, considerably shorter application time and the fuel savings which it makes possible.

It should be noted that the glassflake STC is very hard *and flexible* and therefore remains firmly bonded to the metal or GRP hull even when this is subjected to a great deal of flexing or buffeting as in the case of ice-going vessels or icebreakers.

4. Ceramic-Epoxy

This is a hard, inert coating intended mainly for boats in sensitive waters. A ceramic-epoxy boat coating has been successfully tested in the San Diego area where the University of California Cooperative Extension has been very active in working to help boat owners replace biocidal AF paint with non-toxic coatings. Whether or not it has application to commercial shipping remains to be seen. The ceramic content strengthens the epoxy, resulting in a longer-lasting coating which can be cleaned in the water.

Another version of the ceramic coating combines ceramics with silicone. It is described as a polymer ceramic/silicone hybrid composite.[11] Again, this coating has been used on boats and recreational craft rather than on ships.

These are the main hard coatings which are available and in general use. There may be others not covered.

No attempt has been made to include every single coating available. Some are in developmental or experimental stages and may well become the coating of the future. But these coating systems are the ones in most common use today.

By far the most prevalent coating type in use throughout the world fleet is the biocidal antifouling (AF) coating.

Some estimates place the use of AF paints at 90% of the total fleet with FR coatings taking up the vast majority of the remainder of the fleet and only a very small percentage using hard, inert coatings combined with cleaning. Accurate figures are not available but this will give a general idea of current practices with regard to type of hull coatings in use.

Underwater hull coating maintenance, repair, replacement, cleaning

The most common practice prevalent throughout the world fleet at time of writing can be summarized as follows:

1. Shot blasting, primer, epoxy anticorrosion scheme (usually two coats) and two coats of copper-based, biocidal antifouling paint at newbuild stage.
2. Operate vessel for about two years paying little attention to hull coating condition or biofouling, hoping that the AF coating will be effective, not worrying about niche areas or any threat of spreading non-indigenous species (NIS) via hull fouling.
3. In some cases, after the initial two years, because the antifouling paint loses its effectiveness and particularly because it cannot withstand a lay-up of any length, the underwater hull is cleaned in the water to remove the accumulated biofouling, and this practice is continued in order to try to keep the fuel penalty under control until the next drydocking.
4. Drydock the ship after three to five years, high pressure wash the hull, spot blast and patch any areas of corrosion damage with primer, two coats of epoxy, then reapply two full coats of copper-based biocidal antifouling paint to the entire hull and undock.
5. Repeat steps 2 and 3 (the hull is now rougher after the spot blasting and patching).
6. Repeat steps 2 and 3 (the hull is now even rougher after further spot blasting and patching).
7. After 10 - 15 years, drydock the vessel, blast the entire hull back to bare steel and start again at 2.

This goes on for the life of the vessel.

An alternative approach involves the use of a silicone or fluoropolymer coating but the cycle is similar to 1 - 6 above.

On biocidal AF coatings, in-water cleaning of vertical sides and flat bottom depletes the coating and also causes a pulse discharge of biocides into the water. In-water cleaning of AF-coated hulls is therefore forbidden in most ports. In-water cleaning on FR coatings must be restricted to ultra light cleaning to remove slime; otherwise the coating will be damaged.

In the case of hard coatings on ice-going vessels, the cycle above is varied considerably. Shipowners either use a cheap epoxy coating which is almost entirely scraped off in the winter and needs to be replaced each spring, or they use a specialized ice coating which needs to be repaired or replaced frequently.

The cycle for an STC is as follows:

1. Thorough hull preparation, grit blasting to Sa 2.5 at newbuild or during routine drydocking
2. Application of glassflake STC, two homogeneous coats, no primer, about three hours minimum and no maximum overcoating time, 1000 microns total dry film thickness (DFT)
3. Launch vessel
4. Every month, two months, six months depending on sailing pattern and climate, schedule routine underwater cleaning by divers using industrial/commercial in-water cleaning methods
5. During routine drydocking, pressure wash the vessel if the hull has not been cleaned recently under water
6. Touch-ups as needed on any mechanical damage (anchor chains, etc.)
7. Undock and continue with 4
8. Continue 4 - 7 for the life of the ship.

This is the normal cycle for a ship coated using the STC coating system.

In-water cleaning

For a number of reasons, neither AF nor FR coatings are suitable for in-water cleaning except for the removal of light slime from FR coatings. For environmental reasons, biocidal AF coatings should never be cleaned in the water. In many places the practice is forbidden. There are no cleaning systems which effectively collect all the debris and biocides which are discharged suddenly when biocidal coatings are subjected to in-water cleaning. Additionally, the in-water cleaning damages and depletes the coating, removing 30 - 50% of the remaining coating in a single cleaning.

Similarly, FR coatings are not suitable for in-water cleaning of anything beyond a light slime because the coating itself can easily be damaged by the cleaning process. Once the FR coating has been damaged, it loses the very properties on which it is based and can rapidly become fouled. And there are questions about the environmental hazard posed by these coatings. FR coatings can be kept clean if the cleaning is very light and very frequent.

Despite the unsuitability, the trend is towards increased attempts to clean both AF and FR coatings in the water and, as explained above, this tends to accelerate the coating degradation and increase the fuel penalty which such cleaning is attempting to mitigate.

Hard coatings can safely be cleaned in the water. An STC can be cleaned in the water as often as needed as aggressively as required, with total removal of any type of fouling, without damage to coating or hazard to the environment and become smoother with repeated cleaning.

Non-indigenous marine species

The current basic recommended approach to preventing the spread of NIS through hull fouling consists of an effort to employ an appropriate hull coating coupled with various methods of cleaning the hull and in particular the niche areas to remove fouling without spreading NIS in the process. In theory, the approach is sound. In practice, the hull coatings in widespread use and the existing hull cleaning methods present great challenges to the workability of this approach.

None of the coatings in general use prevent microfouling from adhering to the hull.[12] [13] However, microfouling is not considered to represent any major NIS risk.[14] [15]

None of these coating systems prevent the accumulation of macrofouling organisms in what are commonly referred to as the "niche areas" of the underwater hull. The "niche areas" are the nooks and crannies in the hull, of which there are a great many: sea chests, bilge keels, the areas around the propeller and the rudder, bow thruster tunnels, stabilizer fin recesses and many, many other parts of the ship hull, being protected from the main flow of water along the hull, are prime hideaways for NIS looking for a free ride to a foreign port.[16] The evidence is very plain: examine these areas on a ship hull painted with any of these hull coatings and, unless the area has been specially cleaned, there will be a large accumulation of macrofouling organisms and very likely among them will be invasive species which are definitely not wanted at the destination port.

Macrofouling around the propeller shaft area of a hull coated with biocidal antifouling.

In the case of biocidal antifouling and fouling release coatings, the flow of water as the ship travels is an essential part of their action. These niche areas are protected from this flow. Thus these coatings are not effective in preventing or in releasing macrofouling which accumulates in the niche areas.

These niche areas are also the hardest parts of the hull to clean in the water. The large, multi-brush underwater cleaning machines cannot be used to clean these niche areas. They require smaller power tools or hand tools, high pressure water jet equipment or a combination of these.

However, it is not only the niche areas that accumulate fouling. Even coated with biocidal hull paint or fouling release coatings, the hull of a ship will accumulate macrofouling. It is astonishing how many living organisms populate the marine environment, how ready they are to attach themselves tenaciously to any surface immersed in the water in their vicinity for any length of time, and how tough and resistant they are, regardless of the coating on that surface. Again, the evidence is plain for any diver or ROV camera to see.

There is a further liability involved in an attempt to deal with NIS using biocidal paint coatings. The organisms that do survive and are successfully translocated from one environmental zone to another have been found to become “copper tolerant” or “biocide tolerant” and especially tough, tenacious and resilient and thus more able to establish themselves and to survive in their new environment. In fact, they prove to be tougher than the local species which have not become tolerant to the various biocides in use and it is easier for the invading species to overwhelm the local species and take over.[17 18 19]

Therefore, the idea that one can simply put the “right coating” on the hull and the NIS problem will disappear is a delusion. There is no “right coating” that will, all on its own, prevent the spread of NIS. The closest there was to that concept was TBT, described by Dr. Edward D. Goldberg of the Scripps Institution of Oceanography as, “perhaps the most toxic substance deliberately introduced to the marine environment.” TBT has been widely and quite correctly banned. In fact, some types of coating will worsen the situation by helping to breed tougher and more viable invasive species.

The most prevalent current practices for underwater ship hull protection and biofouling control are not capable of preventing the spread of NIS.

The only known way to remove the offending hull fouling organisms is to clean them off mechanically. Success at this endeavor depends very much on the type of coating system in use and the regularity of hull husbandry practices.

Current propeller maintenance practices

Shipowners/operators, technical superintendents and those responsible for keeping ships operating efficiently are aware of the fuel penalty associated with rough, fouled propellers and it is common for some maintenance measures to be in force to take care of this.

These measures consist of scheduled propeller polishing. Often this is done only when a ship goes to dry-dock. Since this might be every 2 ½ - 4 years, it is nowhere near frequently enough to keep a propeller operating at optimum efficiency.

Some vessel operators therefore schedule in-water propeller polishing, perhaps once or twice per year, which in most cases is still not frequently enough.

Current propeller maintenance practices vary greatly from fleet to fleet and ship to ship. On average, the most propeller efficiency conscious owners/operators schedule propeller polishing every six months or so; a less conscientious approach might result in propeller polishing once a year; in many cases no in-water propeller polishing is done between drydockings.

Yet the evidence is that keeping a propeller clean of anything more than a slime layer, and cleaning before a hard, calcareous layer forms, is far more fuel-efficient and economical, in addition to being safer environmentally.

Very badly fouled propeller.

Current rudder maintenance practices

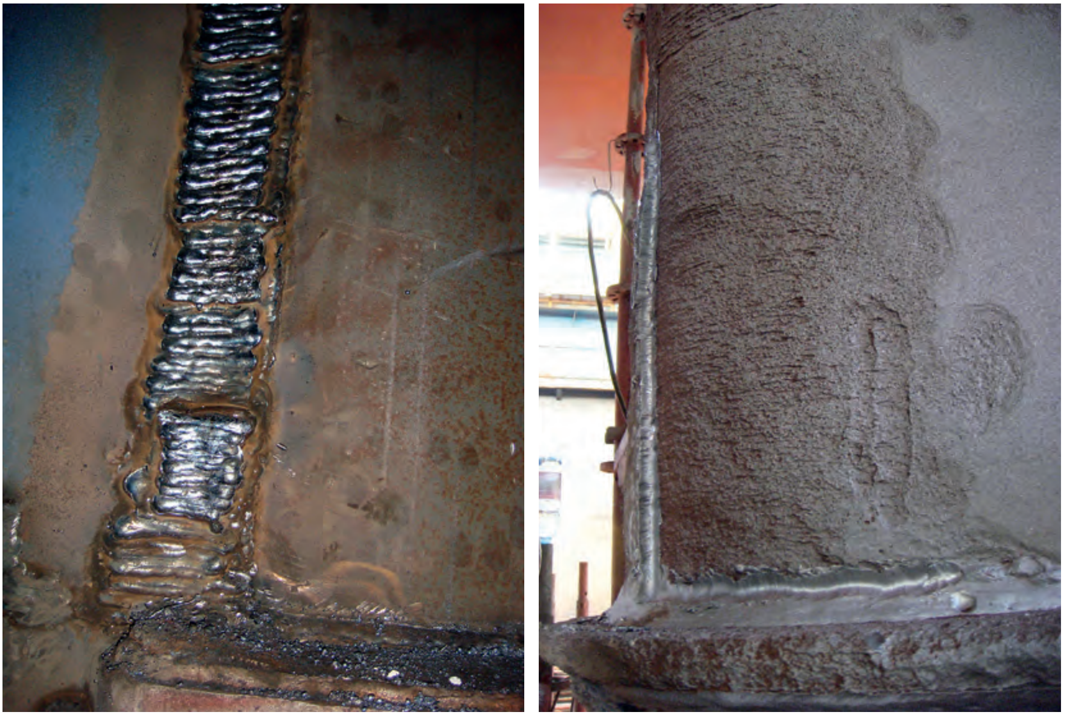
The most common practice is to use a conventional type of rudder, place it directly behind the propeller and coat it with a typical epoxy coating or antifouling scheme consisting of primer, epoxy coats, midcoat and biocidal AF paint; the rudder area is often also surrounded by a number of sacrificial anodes for cathodic protection.

Depending on the design of the rudder, the usual cruising speed of the vessel and the presence or absence of abrasive particles in the water, cavitation erosion sets in rapidly or not so rapidly; the paint is eroded away leaving bare steel; the steel is then subjected to the combined damaging effects of cavitation erosion plus corrosion; the rudder becomes pitted and damaged, usually in a specific pattern; inspection reveals the damage, hopefully before it is too late, and the rudder must be repaired or replaced before it disappears completely.

The repair usually consists of welding to restore and build up the surface where the metal has eroded or corroded away, followed by repainting. Plates may need to be entirely replaced. This usually takes the form of lengthy and expensive hot work performed in dry-dock. Alternatively, it can involve expensive, drawn-out underwater repairs to the rudder to keep it functioning until the next opportunity to drydock the ship. Repairs done under water can only be considered a temporary measure since the steel and the welds must of necessity be left bare.

The vessel sails and the repaired rudder is subjected to further cavitation. Weaker now, the damage occurs more rapidly. Before too long the rudder must be replaced entirely.

This all adds up to a continuing economic nightmare for the shipowner/operator. Drydocking is expensive in many ways, not the least of which is the off-hire time it entails.



Typical repairs to rudders that have suffered cavitation damage.

Current practices with regard to drydocking

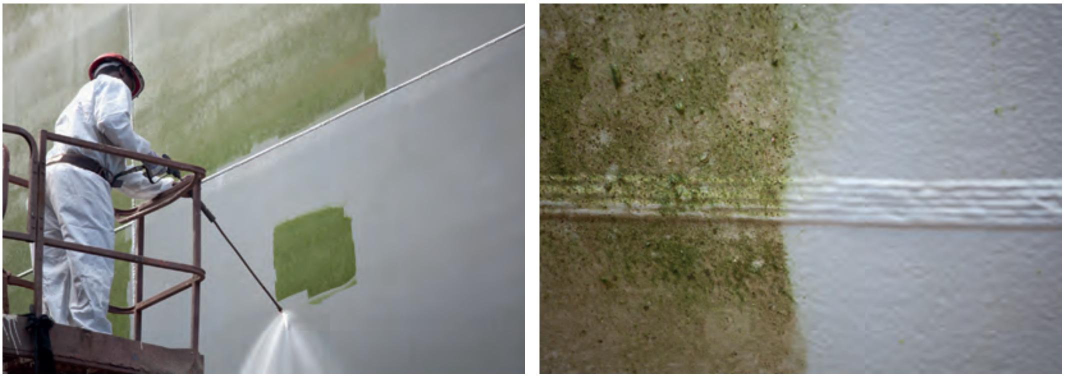
In general, most ships are drydocked every three to five years. In many cases it is twice in any five year period. In some very rare cases, once every seven and a half years. The dry-dock interval is based on State and class requirements and on the need to clean their hulls and repair their antifouling or fouling release hull coating system.

Typically a ship coated with conventional antifouling paint goes through the same procedure every drydocking. The hull is cleaned of biofouling by high pressure water jet equipment, then the condition of the coating is inspected. Rust spots and damaged coating are repaired by blasting and then patching the epoxy anticorrosion system. Then the entire hull is recoated usually with two coats of biocides. This procedure is repeated at each drydocking. The coating becomes rougher and rougher with each attempt to spot repair it. The patches become the next weak link in the system so that each time the vessel comes to dry-dock the coating is in worse condition and needs more extensive patch-up. Eventually after three to five such drydockings the coating is in such bad shape that repair is not possible and it is all blasted off and the entire coating system reapplied, all five to seven coatings of it including primer, anticorrosion system and antifouling coats.

Fouling release coatings follow a similar pattern. It is rather difficult to patch a fouling release coated hull since the non-stick character of the coating is not a good surface for the new paint to adhere to.

Ship in dry-dock showing typical antifouling paint condition after fouling removed.

Ships that use an STC go through an entirely different cycle. The hull is prepared thoroughly, either at newbuild or in a routine drydocking, to Sa 2.5. The STC is applied in two coats of homogeneous material, no primer, no mid coat, no tie coat, no antifouling or fouling release. There is about a three hour minimum time between the coats so the entire coating process is rather quick. The ship sails and the hull is cleaned regularly during service with the ship afloat. Drydocking is not required for paint or fouling removal. When the ship is drydocked for class requirements, the hull is washed if it has not been recently cleaned in the water, and any minor damage, nicks and scrapes are touched up. This is a very short process. The ship is not held up in order for the paint to be reapplied.



STC-coated ship in dry-dock showing typical paint condition after fouling removed.

Chapter summary

In this chapter we have attempted to paint in broad strokes the current practices with regard to ship hull protection and biofouling control.

Current prevailing practices are not the best available practices. Some of them are wasteful and far from environmentally benign. There is great need of change. The inertia is considerable.

In the next chapter we will look at the current forces and factors which are driving change in this well-established status quo.

It is indeed time for the entire shipping industry to rethink its approach to protecting ships' hulls and keeping the marine fouling at bay.

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