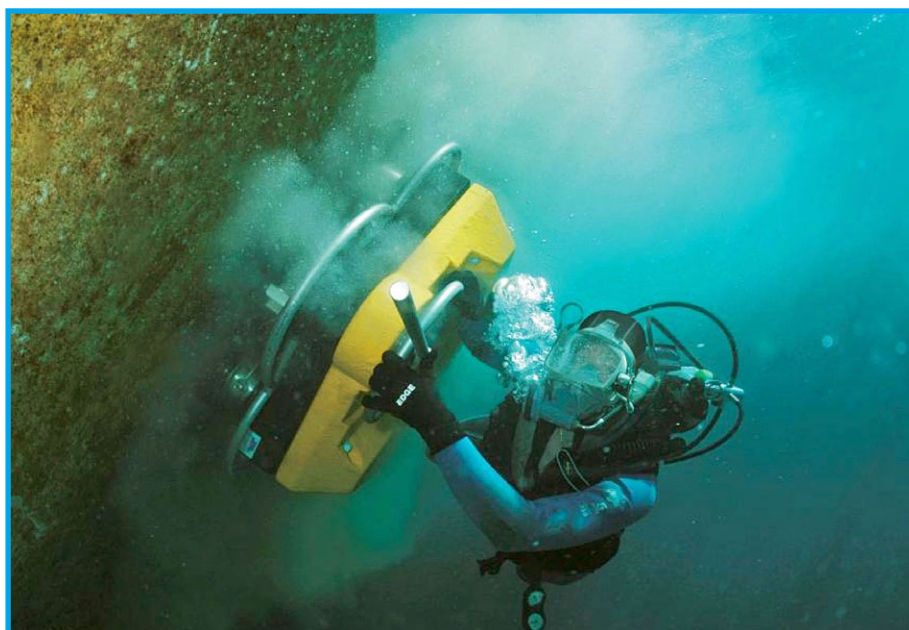


WHITE PAPER

The Slime Factor



Shipowners/operators can gain enormous savings through advanced underwater hull maintenance technology

The Hydrex Group
www.hydrex.be

Part I. Introduction

The overlooked slime factor

It has been well known for millennia that a fouled hull reduces a ship's speed considerably. Nowadays this equates to increased fuel consumption and cost of operation. Shipowners and operators, officers and managers are well aware of this and take steps to reduce fouling as much as possible.

However, fouling is all too often erroneously seen as beginning with the weed or grass stage and increasing in severity through barnacles, clams, sponges, all the way to kelp and larger aquatic plants and animals.

What is all too often missed or disregarded is the effect of the very early stages of biofouling: microscopic fouling or biofilm, commonly referred to in the shipping industry as SLIME.

Within hours of a clean hull being submerged in the sea, bacteria begin to accumulate on that hull, whether or not it is coated with biocidal antifoulants (AF) or silicone or other foul-release coatings (FRC) or anything else. In its early stages, this slime is hardly visible. Yet even a light slime has been shown to increase fuel consumption by 8% or more and a heavy slime can result in fuel consumption increases of 18% or more.¹

That may not appear to be that much. But at today's fuel prices it adds up. And the additional fuel consumption also increases greenhouse gas (GHG) emissions proportionately. The increase in power required to maintain a cruising speed can cause excessive wear to engines. Modern ship propulsion plants are not typically designed with the large power margins that earlier propulsion plants had.

Let's take an example of a cargo ship that requires 100 tons of fuel per day to maintain a cruising speed of 20 knots with a completely smooth and unfouled hull, the way it was at its first speed trials. If that ship were to build up a thin layer of slime in a month and a thick layer of slime in two months, by the end of those two months of sailing, it would be requiring 110 tons of fuel per day to maintain the same cruising speed. Taking fuel at \$450 per ton, the slime build-up would cause a fuel penalty of an additional \$4,500 per day just to keep operating at the same service speed. Even if the fouling remained at that level, in a month it would have used \$135,000 more fuel than it would have if the hull were clean. In a year, at that same rate, it would have cost \$1.62 million more than if the hull had been maintained clean.

Now let's assume that that cargo ship is one of a fleet of 100 similar vessels. If no attention were paid to the slime factor in between drydocking, you can assume that that fleet would waste \$162 million per year in fuel alone, just to overcome the negative effects of slime on the hulls. Of course, every vessel and every fleet would have its own individual figures depending on many variables, and this is a broad

...even a light slime has been shown to increase fuel consumption by 8% or more and a heavy slime can result in fuel consumption increases of 18% or more.

¹ Daniel Kane, "Hull and Propeller Performance Monitoring," presentation SNAME Climate Change and Ships, Feb. 2010. These figures reported by the US Navy for a frigate in 1991.

Increased fuel costs of this magnitude cannot be ignored if the ships are to be kept running economically.

estimate; but it is a fair one. In fact, these figures are conservative.

Increased fuel costs of this magnitude cannot be ignored if the ships are to be kept running economically. There is an additional factor to take into consideration: there is evidence that slime layers make it easier for other fouling such as weed, barnacles and other organisms to adhere to the hull, causing even greater fuel penalties.² This can also lead to damaging the hull coating itself and eventually, adversely affecting the steel under the paint.³

These are the kind of numbers that are being ignored when an owner or operator repaints a ship with traditional antifouling paint or a foul-release coating, after launching or relaunching then pays no further attention to the underwater hull until it's time to drydock again in 2 ½ years.

The information presented here about slime is not new. In 1952, in the book *Marine Fouling and its Prevention* prepared for the Bureau of Ships, Navy Department, by Woods Hole Oceanographic Institution, the following passage appears in the first chapter, "The Effects of Fouling":

As a result of experience over a number of years, the British Admiralty makes an allowance for design purposes for an increase of frictional resistance of ¼ per cent per day out of dock in temperate waters and of ½ per cent per day in tropical waters. The result of this assumed rate on speed and fuel consumption at the end of six months for various types of ships in temperate waters is given in Table 1. In tropical waters such results would be expected at the end of three months (20). In the United States Navy the Rules for Engineering Competition in effect prior to the war allowed for 3 per cent increase in fuel consumption per month (3).⁴

Type of Ship	Standard Displacement Tons	Loss of Maximum Speed (Knots)	Percentage Increase in Fuel Consumption* to Maintain a Speed of	
			10 Knots	20 Knots
Battleship	35,000	1 ½	45	40
Aircraft carrier	23,000	1 ½	45	40
Cruiser	10,000	1 ½	50	45
Destroyer	1,850	2	50	35

Table 1. Effect of Fouling after Six Months out of Dock in Temperate Waters (Frictional resistance assumed to increase ¼ per cent per day.)
*These figures are based on the fuel consumption for propulsion only, i.e. auxiliaries are not included.

2 Woods Hole Oceanographic Institution, *Marine Fouling and Its Prevention*, United States Naval Institute, Annapolis, Maryland, 1952: 44.
3 *Ibid.* 14-19.
4 *Ibid.* 3.

In an excellent article published recently (November 2010) in *Biofouling*, entitled “Economic impact of biofouling on a naval surface ship,” the authors state that, even though antifouling technology has moved on since 1952, Schultz predicted in 2004 a frictional drag penalty similar to that predicted by the Royal Navy allowance mentioned above, for modern copper-based antifouling (AF) paints exposed in the static condition. This prediction was based on towing tank tests.⁵

These facts and figures need to be faced if significant fuel savings are to be obtained, and with them major reductions in CO₂ and other greenhouse gas emissions.

Recognizing the economic impact of slime is only the first step. Once shipowners, operators, managers and ships’ officers are fully aware of the steep penalties to be paid for a fouled hull, even one fouled only with slime, there is the question of what to do about it.

How do the ship’s officers and management determine if there is a build-up of slime and what effect this is having on the ship’s performance? This is simpler than it may seem and will be discussed later on in this paper.

Once it is clearly determined that there is a sufficient slime build-up to warrant attention, how can it be dealt with effectively and economically? This is not always so simple, as will be explained. But there is a workable approach.

Ignoring slime is a costly mistake for any shipowner or operator. It is not something that can be left up to engineers to deal with or not. It is a matter of concern to those responsible for budgets, costs, profit and loss, long term investment value and total ownership cost as well environmental impact of ships and fleets, large or small, military, merchant, offshore, government, sea- or river-going, in cold or warm waters – in other words, any vessel or fleet. It is also of concern to port authorities and to government officials responsible for the environment.

This paper will go into detail on slime and its effect on hull performance and therefore fuel consumption and CO₂ and other GHG emissions. It will discuss various hull coatings in relation to slime. And, because the prevention of slime is not possible with current technology, this paper will also cover the various methods of detection and removal of slime available to shipowners and operators and those responsible for operational costs.

Along with its references, the paper is designed to provide decision makers with sufficient information to devise strategies for maintaining the underwater hulls of ships and fleets at an optimum performance level, thus saving enormous amounts of money while at the same time ensuring that their ships are “good citizens” when it comes to greenhouse gas emissions and other environmental concerns.

⁵ Schultz, M. P. , Bendick, J. A. , Holm, E. R. and Hertel, W. M.(2011) ‘Economic impact of biofouling on a naval surface ship’, *Biofouling*, 27. First published on: 14 December 2010 (iFirst): 88.

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Part II. Slime (biofilm) – what it is and what it does

What is slime?

Biofouling of ship hulls and propellers builds up at varying rates, depending on a number of factors such as the degree to which the vessel is stationary or under way, cruising speed, the waters in which the vessel operates, the condition of the hull and the coating used on the ship bottom.

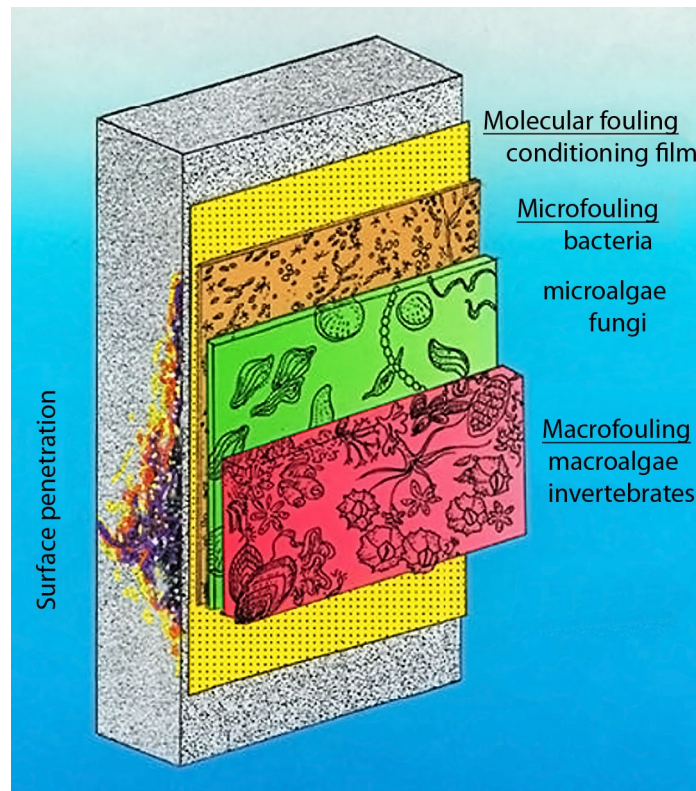


Figure 1. Build-up of marine biofouling (source: Davis and Williamson, 1995)

Regardless of the hull condition and coating used, when a vessel with a clean hull, such as one just out of drydock (or the shipyard if a newbuild), is immersed in water, it begins almost immediately to accumulate the first traces of fouling. This is microscopic fouling. The process is well described in *Marine Fouling and its Prevention*, Chapter 4:

On a newly exposed surface the fouling process usually begins with the formation of a slime film which is produced by bacteria and diatoms [microscopic plants, one of the first organisms in the food chain, a

common component of plankton, which can attach themselves to submerged surfaces]. The bacteria attach and grow rapidly; their numbers on each square centimeter of surface may reach one hundred in a few minutes, several thousand in the first day, and several million in the first forty-eight hours. Algae [seaweed] and diatoms are uncommon during the first two or three days, but then may develop rapidly so that several thousand per square centimeter may be present within a week. Protozoa [single cell animals of the simplest kind] follow. They are generally uncommon during the first week and reach their maximum growth by the end of the second or third week.⁶

The authors also describe this build-up in terms of its effects on frictional resistance:

The Effects of Slime Film on Frictional Resistance

A number of observations indicate that the frictional resistance of a submerged surface may increase with time of immersion in the absence of macroscopic fouling. This effect is attributed to the slime film, formed by bacteria and diatoms, which rapidly develops on surfaces exposed in the sea. For example, in discussing the paper of McEntee Sir Archibald Denny stated that vessels lying in brackish water of the fitting out basin on the river Leven increased their friction nearly ½ per cent per day for several months even when there was no apparent fouling.⁷

...the frictional resistance of a submerged surface may increase with time of immersion in the absence of macroscopic fouling.

This slime layer or microscopic fouling can build up to thicknesses of as much as 2mm,⁸ but the heavier, more visible stages of macroscopic fouling begin when weed or grass starts to grow on the hull, and barnacles and other larger plants and animals attach themselves to the underwater parts of the ship creating even greater frictional resistance.

In his article, “Effects of coating roughness and biofouling on ship resistance and powering,” Research Engineer at the Department of Naval Architecture and Ocean Engineering at the US Naval Academy Michael P. Schultz explains that there are degrees of slime:

Some distinction should also be drawn between light and heavy slime layers. Heavy slime would be a condition where the underlying paint colour is difficult or impossible to determine. In the light slime condition, the underlying paint colour is visible.⁹

Biofilm is as prevalent in freshwater as it is in the sea and in fact forms an even thicker

6 Woods Hole Oceanographic Institution, Marine Fouling and Its Prevention, United States Naval Institute, Annapolis, Maryland, 1952: 42.

7 *Ibid.* 29-30.

8 S. Dürr, J. C. Thomason, Biofouling, Wiley-Blackwell, 2010: 218.

9 Michael P. Schultz, (2007) “Effects of coating roughness and biofouling on ship resistance and powering,” Biofouling, 23:5, 331 - 341

layer in freshwater than saltwater,¹⁰ so river barges and other freshwater vessels are far from immune. This build-up can be seen on the glass of an aquarium or the sides of a swimming pool if these are not kept clean.

All too often slime is ignored and the hull is not considered fouled until seaweed or barnacles can be seen to have attached themselves to the hull. In terms of economy, this is much too late. If fouling has developed to the weed or grass or barnacle stages, the damage has already been done and hundreds of thousands or millions of dollars have already been wasted in fuel burned as a penalty to overcome the added hull and propeller friction caused by the slime.

No hull or coating immune

No matter what the substrata or the coatings used, slime inevitably develops on any surface when it is immersed in water. This includes all antifouling systems currently in use.

No matter what the substrata or the coatings used, slime inevitably develops on any surface when it is immersed in water.

A detailed study of slime by Sergey Dobretsov in Chapter 9 “Marine Biofilms” of the authoritative book *Biofouling* edited by Simone Dürr and Jeremy C. Thomason and published by Wiley-Blackwell in 2010,¹¹ includes the observations that, “Most microorganisms attach more strongly to hydrophobic [water repelling] materials such as Teflon™, than to hydrophilic [water attracting] materials such as glass.” This is interesting to note since silicone-based foul-release coatings are known to be hydrophobic. This is confirmed by Antonio Terlizzi and Marco Faimali in Chapter 12, “Fouling on Artificial Substrata” in the same book.¹² One can therefore assume that these foul-release coatings would lend themselves to a more rapid build-up of slime than would a concentrated glass hard coating for example.

The same chapter contains the statement, “Control and eradication of biofilms are difficult since their resistance towards most antibiotics and biocides is substantially increased compared to planktonic species (see Chapter 11).”¹³ From this one may conclude that traditional antifouling is not effective against slime. This is borne out by the results of experiments described in the book *Marine Fouling and its Prevention* Chapter 2, page 30 which show that various plates, including those coated with biocidal antifoulants, developed slime layers, even if there was a different growth rate of a few days between some of the coatings.¹⁴

In the introduction to their article “The Effect of Biofilms on Turbulent Boundary Layers,” M. P. Schultz and G. W. Swain state:

While modern antifouling (AF) systems are effective in controlling most macrofouling (e.g. barnacles, tubeworms, macroalgae, etc.), they do become colonized by microfouling organisms that produce a slime film. In

10 S. Dürr, J. C. Thomason, *Biofouling*, Wiley-Blackwell, 2010: 138.

11 *Ibid.* 127.

12 *Ibid.* 170.

13 *Ibid.* 124.

14 Woods Hole Oceanographic Institution, *Marine Fouling and Its Prevention*, United States Naval Institute, Annapolis, Maryland, 1952: 29-30.

some cases, the growth of this film is stimulated on copper and organo-tin AF paints (Loeb et al., 1984).¹⁵

It appears that metal-based biocidal antifoulants can actually speed slime growth. Hard coatings also develop slime. No hull is immune. This slime build-up occurs on any hull, no matter what it is made of or coated with. It is a fact of marine life. It is not the case that slime accumulates equally on all surfaces under all conditions. But whatever the surface, whatever the coating, toxic or non-toxic, foul-releasing or not, slime accumulates and increases drag and therefore fuel consumption.

What does slime do?

Many tests have been conducted to determine the effects of slime on the hull and propeller performance of vessels. The results vary somewhat, but they are unanimous in confirming that even a thin layer of slime has a significant effect on underwater hull performance, fuel consumption and consequently CO₂ and other GHG emissions. A thick layer of slime has proportionately more serious effects.

Following are some facts and figures that will make these effects clearer.

In a presentation given by Michael P. Schultz, J. A. Bendick, E.R. Holm and W. M. Hertel at the 15th International Congress on Marine Corrosion and Fouling in Newcastle in July 2010 and subsequently in an article published in *Biofouling* in November of the same year entitled, “Economic impact of biofouling on a naval surface ship,” these experts from the US Naval Academy and the Naval Sea Systems Command (NAVSEA) detail the findings of their economic study regarding hull fouling, which used for its analysis a mid-sized naval surface ship. Their abstract from the article is quoted here in full as it describes their overall findings after a very detailed analysis, very germane to the subject matter of this paper.

In the present study, the overall economic impact of hull fouling on a mid-sized naval surface ship (Arleigh Burke-class destroyer DDG-51) has been analyzed. A range of costs associated with hull fouling was examined, including expenditures for fuel, hull coatings, hull coating application and removal, and hull cleaning. The results indicate that the primary cost associated with fouling is due to increased fuel consumption attributable to increased frictional drag. The costs related to hull cleaning and painting are much lower than the fuel costs. The overall cost associated with hull fouling for the Navy’s present coating, cleaning, and fouling level is estimated to be \$56M per year for the entire DDG-51 class or \$1B over 15 years. The results of this study provide guidance as to the amount of money that can be reasonably spent for research, development, acquisition, and implementation of new technologies or management strategies to combat hull fouling.¹⁶

15 M. P. Schultz and G. W. Swain, “The Effect of Biofilms on Turbulent Boundary Layers,” *Journal of Fluids Engineering*, Vol. 121 / 51, (March, 1999).

16 M. P. Schultz et al., (2011) “Economic impact of biofouling on a naval surface ship,” *Biofouling*, 27: 1, 87 — 98,

...even a thin layer of slime has a significant effect on underwater hull performance, fuel consumption and consequently CO₂ and other GHG emissions. A thick layer of slime has a proportionately more serious effects.

...the cumulative additional operational costs due to heavy slime fouling was about \$1.2 million per year per ship, the largest part of which consisted of increased fuel consumption due to hull fouling...

The DDG-51 class was chosen since it represented 30% in terms of number of hulls and 22% of the wetted hull area of the US Navy fleet, and the ships were widely distributed and therefore subjected to different conditions.

The authors of the article predicted average increases in hull resistance and required shaft power for a DDG-51 destroyer traveling at a speed of 15 knots to be 9% for light slime and 18% for heavy slime.

From this and many other factors they calculated that the cumulative additional operational costs due to heavy slime fouling was about \$1.2 million per year per ship, the largest part of which consisted of increased fuel consumption due to hull fouling (an increase of 10.3% compared to a smooth hull).

Naval vessels may be considered a special case due to their pattern of operation which often requires long periods moored or at anchor, combined with periods of high speed steaming. Nevertheless, these figures are useful to any ship or fleet, from cruise line to VLCCs, offshore oil exploration vessels, RO/ROs and ferries, even if they vary slightly from case to case.

Earlier work by Michael P. Schultz reported in the October 2007 edition of *Biofouling* in an article entitled, "Effects of coating roughness and biofouling on ship resistance and powering,"¹⁷ provided useful conclusions about increased shaft power and fuel consumption required to overcome the effects of various levels of fouling on an Oliver Hazard Perry class frigate (FFG-7). At 15 knots, light slime was predicted to cause an increase in resistance of 11% while heavy slime weighed in at 20%. At 30 knots the resistance caused by light slime was slightly lower (10%) and heavy slime 16%. Various other experiments are cited in this article and all are in general agreement about the effects of light and heavy slime on hull resistance: they are significant.

In recent technical discussions with officers of a passenger ship who regularly monitor hull condition, and brush slime off the hull before it builds up, it became clear that a reduction in speed of 1.5 - 2 knots for a light to medium slime build-up had been observed consistently. The vessel picked back up from 18 or 18.5 to 20 knots at normal cruising RPM when the slime was fully cleaned off the hull by underwater brushing.

The slime factor has been quantified and the results of tests, experiments and predictions are clear: slime has a considerable effect on ship hull performance.

First published on: 14 December 2010 (iFirst)

17 Schultz, Michael P. (2007) "Effects of coating roughness and biofouling on ship resistance and powering," *Biofouling*, 23:5, 331 - 341

Part III. Dealing with slime

At this time there are a few approaches available and in use for dealing with slime.

Approach No. 1: Ignore it

The first and all-too-common approach is to ignore slime. This approach can be adopted through ignorance of the economic effects or from a sort of apathy bred by the problems inherent in trying to control slime on traditional AF coated hulls or the newer foul-release coatings used.

Many shipowners and operators coat their vessels with traditional copper-based and other biocide-leaching antifouling paints and then pay no further attention to the vessel's underwater hull for 2 ½ or 3 years, at which point she returns to drydock and is cleaned and the AF coating partially or wholly renewed. In the meantime the vessel suffers a steady, gradual loss in performance and a significant increase in fuel consumption as the slime builds up; and, as the biocides in the coating are depleted, other fouling accumulates. The cost can be counted in millions of dollars per ship which could have been saved with a more active approach to underwater hull protection and maintenance.

The fact that the performance of the hull is reported by the engineering department to be within the speed limits specified in a charter or within guidelines established by a shipowner or operator, does not mean that the slime is not there or that it is not costing enormous amounts of money to operate under way with this fouling present.

The approach of simply ignoring slime does not provide a positive result and, if practiced, is economic self-destruction on the part of the shipowners, operators, charterers, officers and all those interested in running a vessel or fleet at optimum performance or on a commercially sound basis.

Approach No. 2: Frequent drydocking

The second theoretical approach is to drydock the vessel every few months so as to pressure wash the hull and remove the accumulated slime.

This is very effective in terms of keeping the hull clean. However, it is generally not viable or feasible and is therefore not practiced. It is simply too disruptive to a ship's schedule and too expensive and therefore not worth considering as a possibility at present.

Approach No. 3: In-water cleaning

The third approach is to try to clean the slime off the hull by underwater brushing carried out by divers or automated or remotely controlled devices. This approach is not uncommon. The US Navy's Naval Ships' Technical Manual (2006) provides a full description of how to monitor ship hulls, when and how to clean; it gives detailed

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instructions covering the US Navy's version of this approach.

While various robotic devices and other methods of underwater cleaning have been tried and are being investigated, what it comes down to in practical terms is sending divers down armed with hydraulic machines with rotating brushes which use hydraulic forces to keep them firmly pressed against the side or bottom of the ship while the rotating brushes do their work. They are powered by power packs on workboats or on trucks on the quayside. A variety of brushes can be used for different levels of fouling and different coatings. The brushing units are fairly large with several rotating brushes and can rapidly cover large areas of the hull when placed in trained and experienced hands. Smaller hydraulic brushes or hand brushing are used to clean sea chests and other areas which can't be reached by the larger machines.

Propeller polishing is very much part of the remedy of biofouling but will be taken up as a separate subject in a future white paper as it is a complex subject all of its own. In the real world there is a close connection between hull and propeller monitoring, inspection and cleaning.

Routine, full underwater hull cleaning in between drydockings is the best and in fact only viable approach currently available to handling the slime factor and maintaining the underwater hull at optimum performance.

As will be discussed, the cost and inconvenience of routine monitoring of hull performance followed by underwater cleaning when needed are minor and insignificant when compared to the potential savings in fuel costs and the reduction in GHG emissions thus made possible.

However, this approach has a number of problems inherent in it, stemming mainly from the characteristics of the underwater hull coatings in general use. There is also currently a considerable variance in the quality of in-water hull cleaning and also a broad spectrum of pricing for the work.

Problems with cleaning antifouling (AF) coated hulls

Traditional toxic antifouling coatings are designed to work by gradually releasing or leaching poisonous substances (biocides) into the water adjacent to the ship hull with the intention of killing the organisms that would otherwise become hull fouling. Various ways in which this leaching takes place have been experimented with, in an attempt to extend the useful life of the coatings, but the effect is roughly the same. Over time the active ingredients in the antifouling paint wear out and the coating has to be replaced. Typically this is a 2 -3 year period with the paint gradually becoming less effective over that period. Some manufacturers claim longer life for their products and heavier applications would last longer, at least in theory. But in general these times are accepted within the maritime world by the majority of users of these coatings.

The problems of cleaning AF paints are discussed in some detail by John A. Lewis and Ashley D. M. Coutts in Chapter 24 "Biofouling Invasions" of the book *Biofouling*.¹⁸

18 S. Dürr, J. C. Thomason, *Biofouling*, Wiley-Blackwell, 2010: 357.

Scrubbing antifouling paints prematurely depletes the antifouling coating and creates a pulse of biocide that can harm the local environment and may impact on future applications by the port authority for the disposal of dredge spoil. Depleted antifouling coatings on hulls will also rapidly re-foul, reducing efficiency and increasing marine pest translocation risks. The cleaning process can also increase the pest incursion risk through the release and dispersal of viable plant and animal fragments, or through stimulation of spawning events.

Brushing such a surface in order to clean it results in a heavy discharge of the toxic biocides. What this does is speed up the demise of the coating. The more frequently a hull with an AF coating is brushed or cleaned in the water, the more rapidly it wears out. This then opens the door to more serious fouling or requires more frequent replacement which means pulling the vessel out of the water more often with all the associated costs of drydocking, surface preparation, repainting and the off-hire costs for the vessel. The adverse environmental effects of the increased copper and other biocide discharges into the marine environment are beyond the scope of this paper but will be examined in detail in a subsequent paper in this series.

...hull cleaning can remove 30-51% of one entire coat of antifouling paint.

In a presentation to the National Paint & Coatings Association International Marine & Offshore Coatings Expo in June 2007, Mark Ingle, in charge of materials at the Naval Sea Systems Command (NAVSEA) reported as a key point that hull cleaning can remove 30-51% of one entire coat of antifouling paint.¹⁹

There are two sides to this equation, both of them negative. One side is the accelerated depletion of the active biocides contained in the AF coatings when they are cleaned. This creates a short term improvement in hull performance but a medium to long term degradation of the coating's performance. The other side is that this massive and sudden discharge of biocides caused by cleaning can be acutely harmful to the marine environment where the cleaning is conducted. This is not theoretical. One need only talk to divers who perform underwater cleaning on copper-based AFs to have confirmation of the clouds of toxic red paint that come off the hull under cleaning and the fact that ocean bed and quayside walls are covered with the toxic paint brushed off in the process of trying to remove the slime or other fouling properly. They report that two or three cleanings can leave a mere 5% of the AF coating on the hull.²⁰

Underwater cleaning of AF paints is possible and it is done, but it has considerable drawbacks as discussed here.

Problems with cleaning silicone foul-release coatings

Silicone-based and other foul-release coatings have been proven to be effective in reducing drag when they are clean, and to make it harder for macrofouling (not

¹⁹ Mark Ingle, Presentation to National Paint & Coatings Association International Marine & Offshore Coatings Expo (June 2007): 35.

²⁰ Technical discussions with lead diver Willem Hopmans, (2010).

microfouling or slime) to attach and easier for macrofouling (again, not slime) to be released when the ship is under way, especially at speed. However, they are also notorious for their mechanical fragility and the ease with which the coating can be damaged. This damage extends to cleaning. Even with a soft brush, the mechanical effects of underwater cleaning on this type of coating is to damage the coating by scratching and chipping the rather delicate surface.²¹ Once the surface has been damaged, it loses its effectiveness dramatically.

The cracks or scratches in any hull surface make it easier for fouling to attach. Shipowners and operators are understandably reluctant to use in-water cleaning on foul-release coatings for these reasons. Therefore slime is allowed to build up with all the consequent speed loss and fuel consumption increases already discussed.

Ports forbidding in-water cleaning

Because of the excessive pollution caused when AF coatings are cleaned while the ship is in the water, and due to concern about the threat of invasive species spreading when heavily-fouled hulls are cleaned in the water, some port authorities forbid in-water cleaning of ships in their port. In some cases this restriction applies only to AF-coated or heavily-fouled hulls. In others, it is indiscriminate (though misguided).

The IMO has stressed the importance of port States recognizing and facilitating in-water hull cleaning (2009):

4.22 Propeller cleaning and polishing or even appropriate coating may significantly increase fuel efficiency. The need for ships to maintain efficiency through in-water hull cleaning should be recognized and facilitated by port States.²²

In-water cleaning in general

We will publish a detailed study of in-water cleaning in a future paper in this series as there is more to this subject that can be covered in a few paragraphs, and a full description of the pros, cons and issues will make it easier for shipowners, operators and management to formulate a viable, routine underwater hull cleaning and propeller polishing program for their vessels or fleets.

It is important to know that all hull cleaning is not equal. A thorough, complete, professional cleaning of a large ship hull might cost \$30,000, depending on location. One might find a company locally that will offer to clean the same hull for \$15,000. Even though both suppliers promise the same results, the inexpert, under-equipped company charging the \$15,000 may produce a 30% result with damage to the hull coating due to poor equipment and inexperienced or inept operators; whereas the professional, experienced hull cleaning company will guarantee a rapid, timely, 95% or better cleaning for the higher price. Not removing the slime completely means that

²¹ *Ibid.*

²² IMO Marine Environment Protection Committee 59th Session Agenda item 4 (MEPC 59/WP.8 16 July 2009).

The need for ships to maintain efficiency through in-water hull cleaning should be recognized and facilitated by port States.

In-water hull cleaning needs to be elevated in status to become a key factor in fuel savings and ship hull performance, a major player in reducing pollution of the oceans and the air on a global basis, rather than an irritating afterthought or necessary evil.

within a couple of weeks the officers on the bridge will notice the speedlog dropping a knot or two again and the \$15,000 apparently saved turns into a considerable loss over the period of a few months due to the increased fuel penalty.

In-water hull cleaning tends to be treated as an unimportant activity where the lowest bid gets the job regardless of the results. This can also give in-water hull cleaning a bad name because, trite though it may be, one tends to get what one pays for. In-water hull cleaning needs to be elevated in status to become a key factor in reducing operating costs via fuel savings and ship hull performance, and a major player in reducing pollution of the oceans and the air on a global basis, rather than an irritating afterthought or necessary evil. Such a change in attitude towards hull cleaning will contribute to the creation of a satisfactory worldwide infrastructure of what could be termed industrial underwater hull cleaning, and the overcoming of the current problems associated with it.

Underwater hull cleaning on a properly coated hull (to be discussed later in this paper) should be as routine as bunkering. In fact, a properly equipped, well-trained diver team can carry out the underwater cleaning of the largest vessels in a matter of hours while the ship is bunkering, thus saving off-hire time. This is not a dream. The shipping industry can begin to think along these lines. Increased demand will result in a better quantity and quality of supply.

If a ship is coated with traditional AF paint or a modern foul-release silicone, fluoropolymer or hybrid coating, the tendency is to avoid cleaning for the reasons outlined above. The slime layer builds up. The ship's speed at a given shaft power drops by a knot or two and the vessel requires tons and tons more fuel to complete its usual runs. Spread this penalty over several vessels, a fleet, an entire cruise line or a navy and the costs add up to millions or billions of dollars every year that could have been saved. Spread it across the whole international active fleet and the added unnecessary GHG emissions amount to hundreds of thousands of tons per year that need never have been emitted.

Extrapolated in this way, the slime factor can be seen to be very consequential. To ignore it is to lose.

The real problem with slime

One major obstacle that must be overcome for this system to become the normal routine is the fact that the hull coatings in current widespread use simply do not lend themselves to routine in-water cleaning. The answer to this is also discussed later in this paper. The real problem, the spanner in the works that gets in the way of effectively dealing with slime, is the very nature of most of the hull coatings in current use.

This problem is well-described and analyzed by Dan Rittschof in Chapter 27, "Research on Practical Environmentally Benign Antifouling Coatings," of the book *Biofouling* already cited in this paper:

Antifouling is just one of several very important functions of hull

coatings. Hull coatings are complex multicomponent systems which include anticorrosive and antifouling components [31] (see Chapter 13). Coatings have important physical and anticorrosive properties that include maintaining coating integrity and that have physical properties which maximise hull performance.

Existing commercial solutions to fouling are an uncomfortable and increasingly unacceptable compromise between fouling management, corrosion and environmental degradation. Oxidation control measures cause corrosion and have unacceptable environmental impacts. Similarly, broad-spectrum biocides that must be released and diffuse into organisms to kill them have extensive impact on non-target species and ecosystems.²³

In his incisive and competent analysis, Mr. Rittschhof goes on to put his finger firmly on the problem:

27.6 Practical solutions

The ideal antifouling solutions would be ones that fit within existing business models and polymer systems that managed fouling on hull with minimal impact on other organisms or the environment [4,6,9,45]. Such a solution is possible but would require major changes in research, business and government regulations. This solution requires infrastructure and expertise lacking in industry, government and academia and would require an approach which recognises the needs of business and the environment [6,7]. At present, there is no appropriate infrastructure anywhere in the world that would facilitate generations of ideal antifouling technology. Research teams would be composed of businessmen, chemists, biologists and government officials with the charge of ensuring products minimally impacted environments.²⁴

Such a solution is possible but would require major changes in research, business and government regulations.

In the same chapter he states:

A ship that is a good citizen would minimally impact the environment that it visits. It should be no surprise that existing technologies were developed to maximise efficiency and result in short-term economic gain and to meet the letter rather than the spirit of government regulations.²⁵

This paper and its proposals could be considered in part an answer to the challenge implicit in the above paragraphs.

If there were not an alternative, it would almost be cruel to bring up and point out the problems which currently exist and which appear to have no solution.

²³ S. Dürr, J. C. Thomason, *Biofouling*, Wiley-Blackwell, 2010: 399.

²⁴ *Ibid.* 401.

²⁵ *Ibid.*

Fortunately for all concerned, there is an alternative approach which has been tested, is mature, has been shown to work in many real-world applications, and which can be considered the best available technology at present. Widespread implementation of this solution will require a change of thinking in the industry and in government, no-nonsense legislation on the subject of biocides and pollution, and investment by the marine industry in building the necessary infrastructure to enable a change of gears. This is not a particularly costly proposition and will save shipowners, operators and the taxpayer enormous amounts of money and majorly reduce the impact of shipping on the oceans and the air: very worthwhile targets and with no real sacrifice.

Part IV. Effective address to the slime factor

One of the world's most prestigious cruise lines has been willing to step off the downward spiral created by the AF systems in widespread use, to discover and adopt advanced technology available for hull protection and maintenance. That cruise line has realized significant gains economically with a product and system that has been tested by European governments and found to be entirely non-toxic. Proof of their success is the fact that in ordering two brand-new ships to add to their fleet, to be built by one of the most renowned and forward-looking shipbuilders in the world, they specified the same treatment for the underwater hulls. This cruise line is far from the only shipowner willing to take a risk and break with conventional thought. The solution has been implemented successfully by major shipping lines, icebreakers, RO/ROs, ferries, several navies and a variety of other fleets and vessels.

What does this approach consist of?

The solution has been implemented successfully by major shipping lines, icebreakers, RO/ROs, ferries, several navies and a variety of other fleets and vessels.

1. The coating

A hard coating consisting of relatively large glass platelets in a vinyl ester resin base has been tested for the better part of a decade on a wide variety of hulls and has proved to have extraordinary anticorrosive and anti-cavitation properties and the potential to last the lifetime of the hull with excellent mechanical and abrasive resistance. It classifies as a Surface Treated Composite (STC).

The coating requires a grit-blasted surface. It is usually applied in only two coats amounting to a total dry film thickness of 1000 microns with a minimum overspray time of only a few hours and an extendable maximum overspray time which facilitates a flexible painting schedule. It is most cost-effective to apply it at the new-build stage but it is still highly economical in terms of total ownership cost of the vessel to apply it on a hull previously coated with traditional AF or FR coating systems.

The coating is applied to the vessel only once. It is guaranteed to last ten years but the evidence indicates that it will last the lifetime of the hull. The coating is conditioned after application. This makes it smoother, hydrodynamically more efficient, harder for fouling to attach to and easier to clean if it does.

This coating has been shown to improve with each underwater hull cleaning. It becomes smoother as a very tiny amount of the resin base containing aligned glass platelets is polished leaving a very smooth hull.

2. Routine hull and propeller inspection

Once the coating has been applied and conditioned (the conditioning is done by divers in the water using equipment similar to that used for underwater cleaning) the ship will go into active service.

Because the coating is chemically inert it should also accumulate slime less readily

than AFs which contain copper and other biocides favored by certain bacteria and diatoms which make up the slime layer.

As covered exhaustively in this paper, slime will build up on the surface in varying degree, depending on the water temperature and other factors such as whether the vessel is stationary or under way.

Tools to monitor the ship hull performance are available – indicators on the bridge in combination with regular hull inspections will enable the operators of the ship to act in a timely fashion to remedy a hull fouled with slime. (Inspection and detection of the need for cleaning will be covered in more detail in yet another paper in this series.)

The slime layers can often be seen by visual inspection of the hull at the waterline. When indicators are noted, a trained hull-monitoring diver (one who is knowledgeable in degrees of fouling and competent to conduct inspections) should be sent down to conduct a survey of the state of the underwater hull and propeller condition. Routine underwater maintenance schedules are key to monitoring the condition of your ship hull.

Slime will inevitably accumulate and will have an effect on fuel consumption. This must be detected, confirmed and dealt with rapidly. Every day the slime is left unattended to, once it has built up to a point that it impacts significantly on fuel consumption, is a day when thousands of dollars have been wasted.

3. In-water hull and propeller cleaning

If the vessel is not close to a drydocking scheduled for other maintenance reasons, then competent, professional in-water cleaning of the hull must be scheduled and carried out. This is a big subject and will be covered in a future paper in this series. The cleaning is carried out with minimal adverse effect on the ship's scheduled operations. It need only take 6 - 12 hours to do a full and complete cleaning of the hull of any vessel. The propeller can also be polished if indicated.

With this glass-platelet, hard STC the surface improves with each cleaning over its initial conditioned state. Over time one can observe improved performance and increased resistance to adhesion of slime and other biofouling.

4. Repainting

The most that will be required in drydock will be minor touch-ups. In all cases inspected to date this has amounted to less than one percent of the entire wetted hull surface which required any new paint. This makes the drydocking much easier and quicker for the ship. Painting with conventional paint is known to interfere with other drydock activities and can add a great deal of time to the drydock experience.

General comments on this approach

The elements of this approach all exist in fully developed and tested form at time of writing. Many shipowners and operators have seen the benefits and have adopted the

Every day the slime is left unattended to, once it has built up to a point that it impacts significantly on fuel consumption, is a day when thousands of dollars have been wasted.

hard coating and routine in-water cleaning approach to underwater hull performance and maintenance. They are reaping the economic benefits and competitive advantage while at the same time being good citizens as far as pollution and GHG are concerned. They have noted no liabilities or sacrifices.

This technology is available now for use by any shipowner, operator, any navy, any fleet. However, for this to be rapidly implemented on an industry-wide basis for all ships and fleets, the obstacles enumerated by Dan Rittschof as outlined above need to be exposed and overcome.

1. Shipowners and operators need to subscribe to the cost saving and environmentally beneficial procedures outlined in this paper.
2. Port States need to realize that there is no risk involved with in-water cleaning if certain standards are adhered to:
 - a. That the hull being cleaned is protected by a hard, inert coating that does not contain any toxic substances and will not pollute the port.
 - b. That a hull cleaned frequently, preferably in the case of a badly fouled hull before sailing (i.e. before moving from one environmental zone to another), is the best means of avoiding the spread of invasive species. This is the responsibility of the shipowner/operator but port States can cooperate.
 - c. That the cleaning be performed professionally, completely and to a high standard.
3. Shipowners/operators must “take the plunge” and invest the time and money needed to grit-blast their ships’ wetted hull area and re-coat them with advanced technology glass/resin coatings. The initial investment will be repaid rapidly, and in terms of total ownership cost this approach is an excellent investment in almost all cases (the exception being perhaps vessels that are almost at the end of their useful service).
4. Governments and international organizations should take steps to introduce legislation which bans the use of harmful metallic biocides, as well as harmful herbicides and fungicides as means of preventing fouling. These antifoulants are not effective against slime, and hulls should not be allowed to foul beyond a light slime at most. The biocides are poisonous and have many harmful effects, some lethal, on marine life, fish, the food chain and human beings. As there is a more cost-effective and economical way to deal with fouling effectively, there is no excuse to go on spreading pollution and poison. The coating applied to any vessel’s hull should be inert and not leach or dispel any sort of toxic substances into the water. There should be no compromise on this. The apparent commercial interests of shipowners are no excuse to continue poisoning the oceans, since the non-toxic approach is more economical than the toxic one.
5. The marine industry in general and governments must invest in this advanced technology, particularly on the infrastructure needed to make it possible to deliver in-water cleaning easily and competently on an industrial/commercial level around the globe so that schedules are interrupted less by cleaning than they are by bunkering.

Governments and international organizations should take steps to introduce legislation which bans the use of harmful metallic biocides, as well as herbicides and fungicides as means of preventing fouling.

Part V. The Ecospeed/Hydrex approach

This paper is not intended to encompass a survey of available hard coatings. There have been several epoxy-based coatings over the years and the glass-platelet technology was used in the earlier formulations of certain specialized icebreaking/icegoing hull paint. There is considerable research under way on the subject of non-toxic hull coatings.

Suffice it to say here that there is a glass-platelet, vinyl ester resin based coating which meets all of the specifications already listed: Ecospeed®. It is available now for commercial application and has been for the last eight years.

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The Hydrex Group

The Hydrex Group, an international underwater hull performance, protection, maintenance and repair organization, is one of several suppliers capable of delivering high quality in-water ship hull cleaning on a global basis.

Not only has Hydrex developed Ecospeed as the ideal underwater hull coating, but has also invented and engineered a full line of advanced hydraulic underwater hull cleaning equipment designed specially to condition and clean Ecospeed-coated hulls but which is also usable on any other hull coating.

Worldwide underwater hull cleaning services

Hydrex has also recruited and trained a team of underwater hull cleaning and repair experts to deliver standard cleaning and repair of a very high quality. In addition to setting up satellite offices in strategic locations, the company has built up a network of local suppliers of underwater hull inspection, cleaning and repair as well as propeller polishing and related underwater hull services. In this way Hydrex guarantees its underwater hull maintenance and repair services around the world. Ecospeed itself is guaranteed to last intact on the hull for a full 10 years and that is a conservative guarantee which the company is currently considering extending.

Hydrex has been developing its own underwater hull protection and maintenance system for several decades, based on an equal concern for the avoidance of pollution of the oceans and air and for the economic benefits to be derived from keeping ship hulls free of fouling, thus reducing fuel consumption and emissions. Both these factors have been taken into account and the best possible approach to the problem of hull protection and fouling has been developed.

Inquiries and information

We invite inquiries. We stand by to answer questions, provide references, disseminate information and help you with your specific vessel or fleet situations.

Free initial consultation for your vessel of fleet

We offer a free initial consultation to any shipowner, operator, charterer, navy representative, government official or officer, academic institution and anyone else who can benefit from the most advanced approach we know to the problems of underwater ship hull performance.

Future white papers and journal

We will be writing and distributing a series of white papers, each of which will go into one or more aspects of underwater ship hull performance in more depth and detail. This is the second white paper in the series, the first one being an overview of ship hull performance. Much of the information has already been researched and written up but this is often in highly technical papers of specialized distribution not necessarily easy for shipowners and operators to come across or digest.

In early 2011 we will also be launching a quarterly journal of ship hull performance which will feature these white papers as well as related articles, news and information of interest to shipowners, operators and other decision makers in the marine industry.

If you would like to receive these white papers and/or the journal on an ongoing basis, please sign up on line at http://www.hydrex.be/white_papers.htm or write to us, email us or phone us with your request. Let us know if you prefer electronic or paper copies of the white papers and journals. These are all provided to you free of charge and without obligation.

Vessel or fleet operational costs assessment

Find out if your operational costs for your vessel(s) or your fleet could be drastically reduced by changing your approach to underwater hull protection and maintenance.

To obtain a free initial consultation on ship hull performance for your vessel(s) or fleet simply send an email to the following email address with “Free Consultancy” in the subject line and information about your vessel or fleet and an expert will get back to you promptly:

performance@hydrex.be

To find out more about Ecospeed and Hydrex, visit the following websites:

www.hydrex.be

www.hydrex.us

www.ecospeed.be

If you would like to be added to the mailing list for future white papers on ship hull performance and related subjects and/or copies of the quarterly journal *Ship Hull Performance* please send us your request at the following email address:

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For comments, input, information about the content of this white paper or any communication relating to it, please send an email to the above email address and we will respond.



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