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Hull roughness and antifouling paint

Abstract

The fouling of ships and propellers results in a reduction of speed, increased fuel consumption, and consequently, losses of both time and money. The previous studies found that a speed reduction of 0.03 knots would occur due to increased friction resulting from 10µm increase in surface roughness. This would increase fuel consumption by 1%, energy savings can then be easily converted into emission reductions. The main objective of this paper is to help shipowner/operator (to select) utilizing antifouling paint to prevent fouling for economic and environmental requirements.

Various types of antifouling paints have been used to prevent fouling. Traditional paints contain heavy metals, such as tin, copper, lead and arsenic, all of which release toxic biocides into the water. Tin-containing or tin-base antifouling has proved its excellent technical performance since it has been introduced in 1974.

In the early 1980s, when the environmental problems associated with Tributyltin (TBT), antifouling paints were starting to appear and research and development programmed on a generation of tin-free antifouling paint technology was started that focused on finding solutions to the environmental problems and under water hull performance.

A fouled hull increases the environmental impact on shipping. If the world fleets were today fouled, an extra ~16.5 million tones of fuel would be burned, leading to an increase in air pollution which is represented by an extra 210 million tones of CO2. A fouled hull causes a series of risks of transporting unwanted organisms into sensitive ecosystems. A fouled hull forces a vessel to dock, thus, increasing pollution from shipyards. Fouling release is an antifouling paint which is normally silicon-based. It is a non toxic coating alternative to antifouling paints which leaves a non-stick surface.

The performance of the silicone antifouling release coating improved by adding nonbonding silicone oil to the coating matrix. Fouling organisms may grow on the surface of these coatings. However, these organisms adhere poorly and can be removed by the hydrodynamic forces once the vessel attains sufficient speed.

Foul release coating systems are designed with a low surface energy to reduce the ability of marine fouling to permanently adhere to the hull coating while the ship is underway. The hydrodynamic forces, produced by the moving vessel, cause marine fouling to wash off the hull once the vessel attains sufficient speed.

The use of the silicone antifouling release coating on underwater hull and propellers has generally been found to be successful since they do not last long see a noticeable performance improvement after each cleaning.
propeller being reported in 1993.

وهناك أنواع عديدة من الدهانات استخدمت لمنع تكوين الحشف(الكائنات البحرية)على الجزء المغمور من بدن السفينة منها الدهانات المحتوية على الرصاص وأتت بنتائج مرضية منذ عام 1974 ولكنها تقضي على الكائنات البحرية.

وفي عام 1980 بدأت تظهر الدهانات الصديقة للبيئة البحرية الخالية من المواد السامة التي تحقق حماية الجزء المغمور من بدن السفينة من تكوين الحشف والصديقة للبيئة والغير سامة.
وأخيرا ظهرت الدهانات التي لا تعتمد على---- ولكنها تعتمد على نعومة ملمس السطح وبالتالي تقلل من التصاق الكائنات البحرية (الحشف) ببدن السفينة وعندما تبحر السفينة وتزداد سرعتها حتى تصل الى سرعة الابحار تنفصل هذه الكائنات البحرية.

الحشف على بدن السفينة والرفاصات ينتج عنه تقليل سرعة السفينة وزيادة إستهلاك الوقود وبالتالي فقد الأموال و تأخير الوقت (تعطيل سير العمل).
الدراسات السابقة أوضحت أن زيادة خشونة هيكل الجزء المغمور من بدن السفينة بمقدار 10 ميكرون أدى إلى نقص سرعة السفينة بمقدار 0.03 عقدة وزيادة استهلاك الوقود 1% وهذه الزيادة في إستهلاك الوقود أوالطاقة----------
والهدف الرئيسي لهذه البحث هو منع تكوين الحشف للأسباب الإقتصادية والبيئية.

1. Introduction

International merchant shipping is a highly economical optimized business. Fuel cost is a major operating cost of most merchant ships. Ship designs are usually fairly well optimized with respect to maximum profitability. Thus, one should expect that there is not much efficiency to be gained by a better design and selection of propulsion systems without changing the external economic conditions. The energy savings obtained by application of current technology within hydrodynamics (hull and propeller) on exist ships. Energy savings can then be easily converted into emission reductions.

Anti-fouling paints are used to coat the bottoms of ships to prevent sealife such as algae and mollusks attaching themselves to hull; thereby slowing down the ship speed and increasing fuel consumption. In the early days of sailing ships, lime and arsenic have been used to coat ship's hulls, until the modern chemical industry developed effective anti-fouling paints using metallic compounds.

These compounds slowly "leach" into sea water, killing barnacles and other marine life that have attached to the ship. But the studies have shown that these compounds persist in the water, killing sealife, harming the environment and possibly entering the food chain. One of the most effective anti-fouling paints which contains the organotin tributylin (TBT), has been proven to cause deformations in oysters and sex changes in whelks.

The 1990 IMO's Marine Environment Protection Committee (MEPC) adopted a resolution which recommended that governments adopt measures to eliminate the use of anti-fouling paints containing TBT.
In November 1999, IMO adopted an assembly resolution that called the MEPC to develop an instrument, legally binding throughout the world, to address the harmful effects of anti-fouling systems used on ships. The resolution called for a global prohibition of the application of organotin compounds which act as biocides in anti-fouling systems on ships 1 January 2003 and a complete prohibition by 1 January 2008.

2. Types of hull roughness

Hull roughness is defined as the maximum peak to trough height, expressed in microns as shown in Fig. (1).

One of the factors affecting a ship's performance and fuel consumption is the roughness of the underwater hull. The condition and type of the anti-fouling paint system can have a major influence on hull roughness and ship performance.

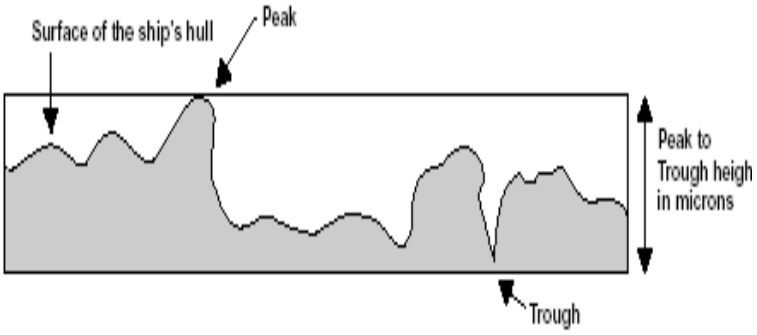

Fig. 1: Surface of the ship's hull (Townsin, 1980)

There are two main types of hull roughness as shown in Figs. (2&3): physical and biological (fouling), each with their own macro (large scale) and micro (small scale) physical characteristics [Maureen, 2002].

- ♦ Macro physical roughness can be attributable to plate waviness, plate laps, welding and weld quality, mechanical damage and corrosion.
- ♦ Macro biological roughness is typically attributable to animal and weed fouling.
- ♦ Micro physical roughness can be attributable to steel profile, minor corrosion and coatings condition.
- ♦ Micro biological roughness is typically attributable to slime fouling.

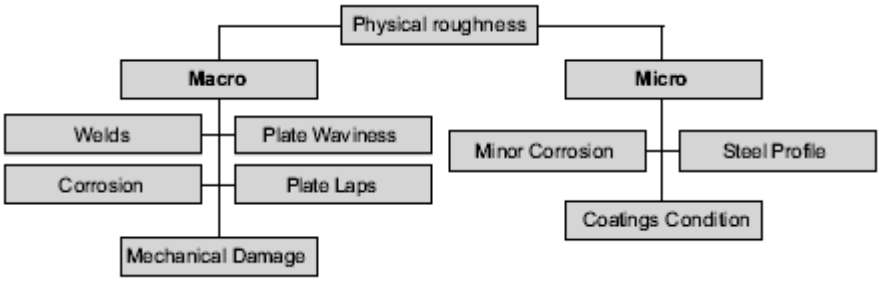

Fig. 2: Macro micro physical roughness [Maureen, 2002]

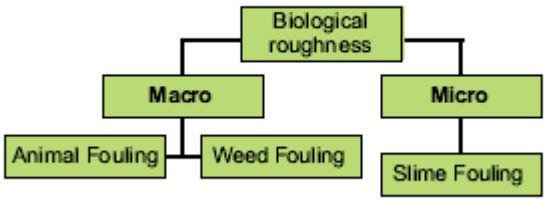

Fig. 3: Macro micro biological roughness (Maureen, 2002)

3. Hull roughness and ship resistance:

Any increase in underwater hull roughness will increase ship resistance or vessel drag, resulting in an additional power requirement with increased fuel

consumption and cost to maintain vessel speed. Conversely, maintaining constant power will result in decreased vessel speed and longer voyage times. In order to consider limitations in technological development, the nature of ship resistance is initially briefly described. A simple and common way of expressing ship resistance is:

Total resistance = Viscous Resistance + Residual Resistance

Viscous resistance is related to the skin friction between the hull and the water. It is commonly divided into a part dependent only on the speed and the area of the underwater part of the hull, and a part dependent on the three-dimensional shape of the hull. In addition, it is common to add a fraction dependent on the quality of the hull surface.

Residual resistance is mainly composed of wave resistance, but covers all resistance components not included in the definition of viscous resistance given above. Such components can have wave breaking resistance, spray and air resistance and so on. Air resistance is of minor importance for conventional merchant ships, but might be of significance for high-speed vessels (of the order of 20% of total resistance), residual resistance depends mainly on the speed and hull shape. Residual resistance is usually presented as a function of the non-dimensional Froude number. Fig. (4) shows the relation between the residual resistance coefficient and the Froude number [IMO, GHG Emission, March 2000].

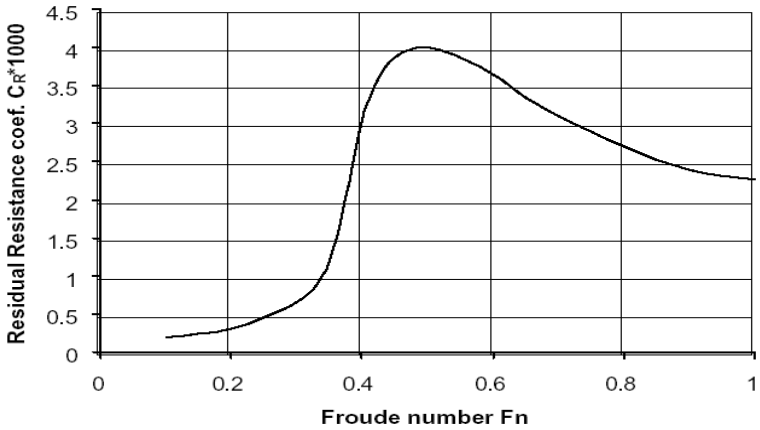

Fig. 4: Relation between Froude number and residual resistance [Muckle's, 1987]

4. The impact of hull roughness on the GHG emissions

Greenhouse gas (GHG) is a gas which does not absorb radiation of wavelengths in the visible light spectrum, but absorbs infrared (heat) radiation. In the atmosphere, these gases allow energy from the sun to reach the earth's surface, but limits infrared energy (heat) from escaping.

CO2 is the most important GHG emitted to the atmosphere, which arises mainly from the use of fossil fuels. The increasing usage of fossil fuels has led to higher concentrations of CO2 emissions (approximately 85% of the world's

commercial energy needs are met by fossil fuels). CO2 accounts for over 80% of the anthropogenic GHG effect. Anthropogenic emissions of greenhouse gases are causing global warming with sea level rise, and acidification of the sea [IMO, Circ.439, 2005].

These emissions are a direct result of fossil fuel combustion, of which international shipping accounts for approximately 2% of the world's total CO2 emissions. The total fossil fuel oil consumption of the world fleet (including military vessels) is ~ 330 million metric tones annually [James J. Corbett, 2003].

If the world fleets were totally fouled, more than 16.5 million tones of fuel would be burned, this represents approximately 5 % of the annual sales of fuel to international shipping, leading increased air pollution by an extra ~ 0.5 million tones of CO2 (CO2 = 3.17 kg/tone fuel). A fouled hull causes a series of risks of transporting unwanted organisms into sensitive ecosystems. A fouled hull forces a vessel to dry docks; thus increasing pollution from shipyards [R. L. Townsion, 1986].

5. Hull roughness and economic consequences

The economic consequences of hull roughness can be seen in the following figures, which relate increasing surface roughness to the percentage increase in power required to maintain speed as follows:

5.1 Hull roughness and antifouling paint type

The two curves in Fig. (5) represent typical upper and lower hull roughness measurements for non smoothing antifouling. Roughness can increase from 75µm to 250µm within two years, representing an extra 15% power requirement to maintain speed.

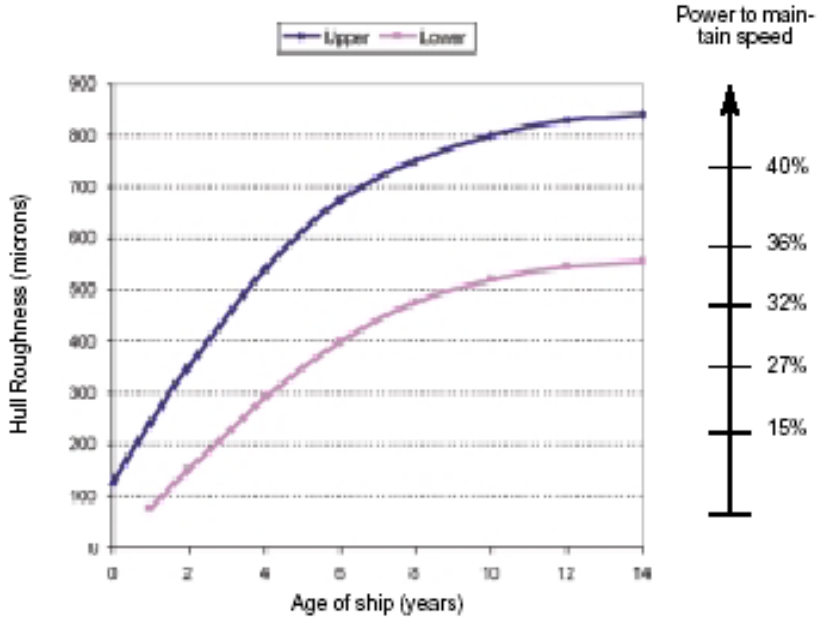

Fig. 5: Hull roughness and antifouling paint type [International Propeller, 2003]

Fig. (6) shows the increase in power required and hence the typical increase in fuel consumption necessary to maintain vessel speed of a fast, fine ship (e.g. Container Liner) versus increasing physical hull roughness.

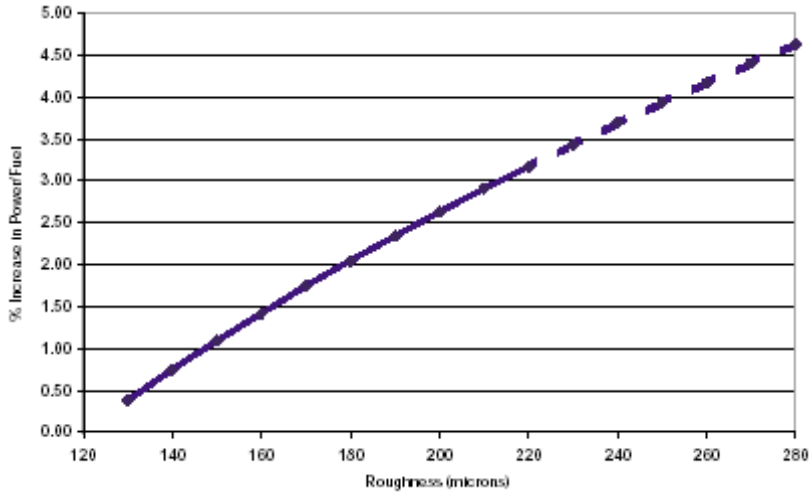

Fig. 6: Typical increase in power/fuel required to maintain vessel speed above 225 microns hull roughness [International Propeller, 2003]

6. Types of antifouling paint

6.1 Self-polishing copolymer paint (tin-base)

Most ocean going ships used (SPC) antifouling, which allowed a constant emission of a virulent toxin, tributyltin (TBT). The proven performance of five years of foul-free operation persuaded ship operators to extensively use SPC coatings. The increasing use of organo-metallic biocides such as TBT on ships and the flushing of residues after coating and bottom maintenance in dry dock, led marine biologists to examine the effects of these toxins on marine life. As is well known, this gave rise in 2001 to its prohibition by the International Maritime Organization (IMO) of further application of TBT SPC after 2003, followed by a complete phase-out of their use by 2008 [C. Anderson et. al., 2003].

6.2 Alternatives to tin-based antifouling paint

There are three main categories of tin-free antifouling paints:

6.2.1 Controlled Depletion Polymer (CDP) paint

CDP was the first type of tin-free antifouling paint to be released on the market. The price is almost similar to that of traditional paints and the coating is reliable for up to three years. The dissolution is slow, similar to the way soap dissolves in water due to the rosin content, which is slightly soluble in water. CDP is based on copper. It also contains some very strong boosting

biocides. The biocides are released by diffusion, the dissolution gradually slows down due to a leached layer formed by insoluble materials at the surface. The roughness of the surface and fuel consumption will therefore increase as time passes.

6.2.2 Hybrid TBT free paint

By carefully combining patented Copper Acrylate technology with Rosin based CDP technology, it has been possible to form a hybrid. Hybrid is an antifouling which has the CDP features of surface tolerance and attractive volume solids, control of biocide release and reduced leached layer size. Since CDP and Hybrid antifoulings are not designed for more than 36 months in-service on the vertical sides of a vessel, the power/fuel penalty for these products rises sharply after three years.

6.2.3 Self-Polishing Copolymer (SPC) paint

SPC is, as the name suggests, a self-polishing paint which matches the performance of traditional TBT-based coatings as it is based on a chemical reaction between water and the coating.

The service life of SPC is up to five years. It costs 2-3 times more than the CDP paints. SPC contains smaller amounts of biocides than CDP and is also less toxic. The base is copper as in CDP, but the amount needed is only two-thirds to that of CDP. The other biocide used in SPC is generally zinc pyrithione. The function is based on a chemical reaction with water (hydrolysis). SPC has a more controlled leakage of biocides over time which reduces the risk of fouling.

6.2.4 Fouling Release paint

Fouling release is an antifouling paint, which is free from biocides. It is normally silicone-based and leaves a non-stick surface . The efficacy is dependent on the speed of the vessel as any attached fouling is supposed to wash off. Moreover, the price is a major disadvantage since it is being 5 times more expensive per liter than others. However, as evaluations on expected service life continue and if the Fouling Release coating is intact, no re-coating is needed for several years, which in turn reduces costs. This paint is one of the best choices on the market when it comes to environmental impact as it contains no biocides. The effect is based on a smooth surface where organisms have trouble attaching. When the vessel increases speed, the organisms fall off [C. Anderson et. al., 2003].

7. Physical hull roughness of different antifouling types

Hull roughness studies were carried out for a typical fast line container ship. These studies showed that ships generally get rougher due to mechanical damage from anchor chains, tugs, berthing, etc. and from detachment, cracking, and corrosion etc. of applied surface coatings. The increase in roughness was found to differ markedly depending on which antifouling type was used as follows:

- For Controlled Depletion Polymer (CDP) antifouling, the average hull roughness (AHR) increase of these coatings is estimated at 40 microns/year.
- For Hybrid TBT Free antifouling, offers a balance of CDP type and SPC type antifouling properties with performance and AHR increase assumed to be midway between the two at 30 microns per year.
- For Self Polishing Copolymer (SPC) antifouling, the average increase was found to be significantly less, at 20 microns increase in AHR per year. This reduction is a result of the polishing and smoothing action of SPC antifouling.
- For Foul Release antifouling, the AHR increase is assumed to be only 5 microns per year. These products do not use biocides to control fouling but rely on a “non-stick” surface to make it difficult for fouling species to adhere. Foul release systems provide a very smooth surface [R. L. Townsion et al., 1986].

The increase in power required over time for the four main antifouling technologies outlined based on their average increase physical hull roughness per year. The initial roughness is taken as 120 microns which is the approximate roughness value for a typical new building as shown the results in Fig. (7).

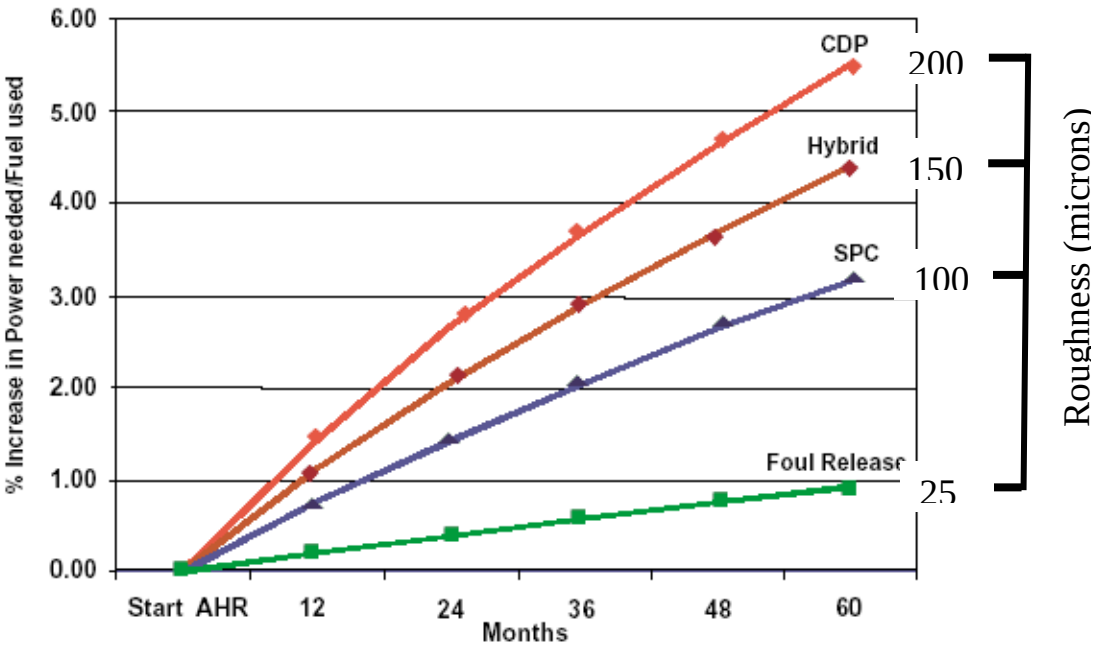

Fig. 7: Estimated increase in power needed/fuel used due to increasing physical roughness of different antifouling types over time [C. Anderson et. al., 2003]

8. Enhancement of foul release coatings of by Oil Incorporation

Fouling release coatings have been developed as an alternative to biocide-containing paints. They function by minimizing the adhesion strength of attached organisms, which are removed as the vessel moves through the water [Maureen, 2002].

Oils can enhance properties of foul-release paints. Oils by their nature are lubricants and therefore should decrease the coefficient of friction. It has been found that incorporation of low molecular weight silicone polymers oils can enhance foul-release properties of polymerdimethylsiloxane (PDMS) polymers [Stein J., et. al., 2003].

The method for the enhancement of fouling release performance has been oil incorporation, in which a polymerdimethylsiloxane PDMS oil was incorporated into a silicone matrix.

In order to quantify the effect of oil inclusion on fouling coverage, panels coated with the PDMS oil and without it were immersed at Miami Marine Research and Testing Station (MMRTS), University of Hawaii, and the two Northeastern sites. At all of the exposure sites, total coverage was slightly less for the PDMS coatings containing oil as shown in Fig. (8).

This is also illustrated in Fig. (9), which shows photographs of the panels coated with the two formulations and exposed for approximately one year at the U. of Hawaii site. The panel on the left was coated with the PDMS topcoat, and

the panel on the right was coated with the PDMS oil topcoat [Callow et al., 1988].

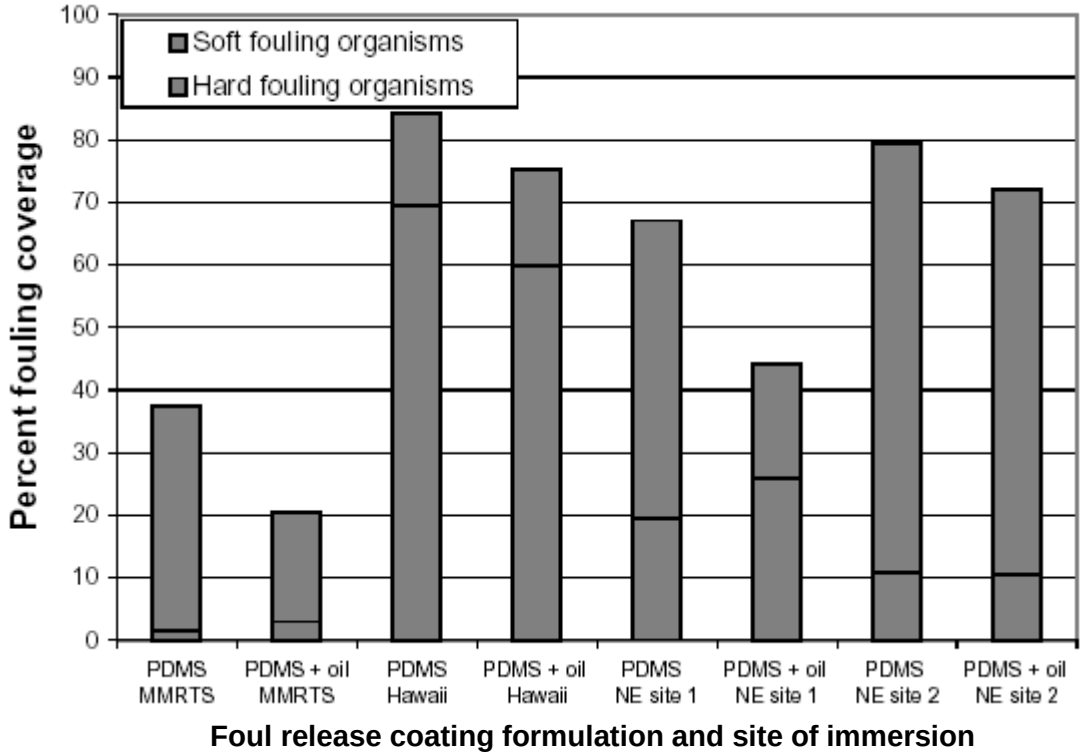

Fig. 8: Effect of foul release coating with oil formulation on percent coverage of fouling organisms at four exposure sites [K. Truby et al, 2000]

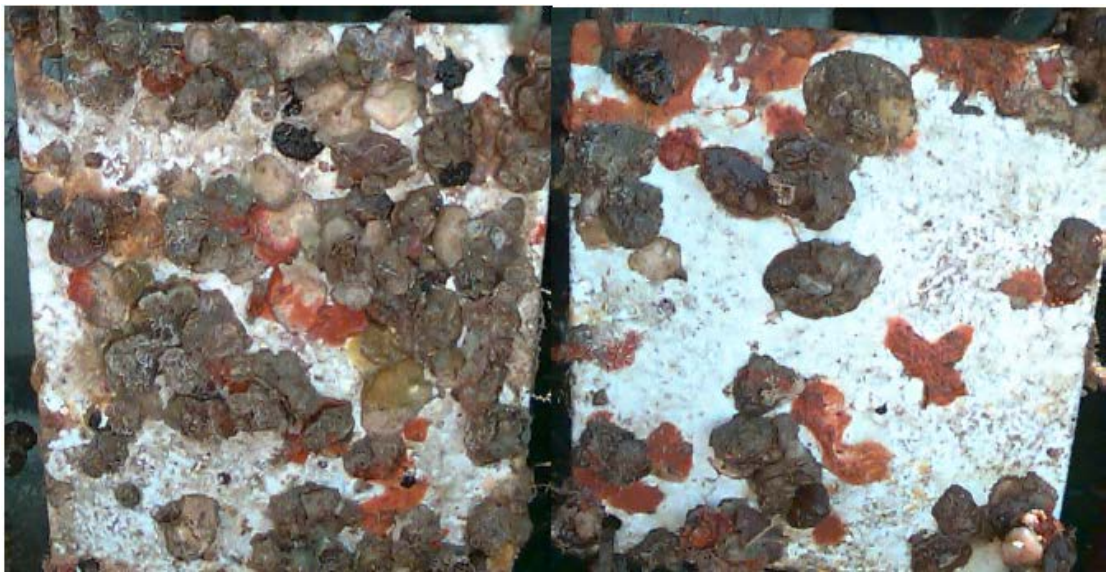

Fig. 9: Photographs of panels exposed at U. of Hawaii fouled with hard and soft fouling organisms [K. Truby et al, 2000]

Previous research suggested that incorporation of foul release PDMS oil reduced total coverage and might enhance ease of removal of fouling. This expectation was confirmed in the barnacle adhesion data obtained from Florida

Institute of Technology (FIT), which showed that the addition of oil to the PDMS significantly increase shearing stress and decrease barnacle adhesion strength as shown in Fig. (10).

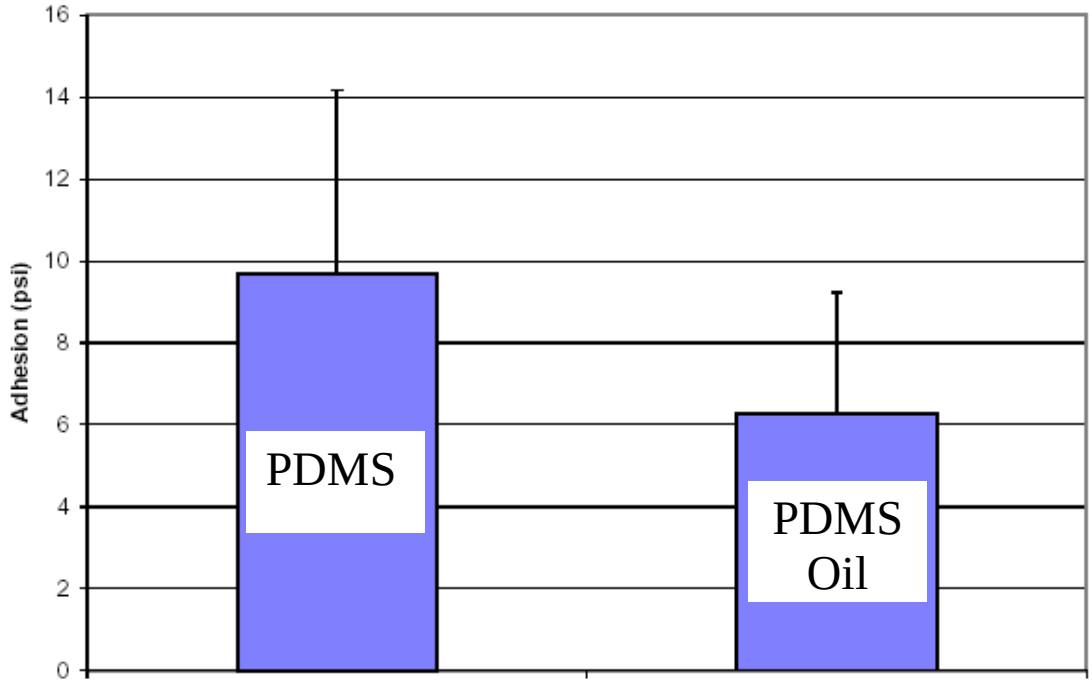

Fig. 10: Effect of PDMS oil addition on mean barnacle adhesion strength [K. Truby et al, 2000]

Drag measurements were carried out in towing tank experiments with two friction planes of different size (2.5m and 6.3m long), which showed that the foul release system exhibits less drag than the tin-free SPC system when similarly applied. The difference in frictional resistance varied between about 2% and 23%, depending on the quality of application as reported [Candries M., et al., 2001].

A study of the boundary layer characteristics of the coatings was therefore carried out in two different water tunnels using four-beam two-component, The measurements show that the friction velocity for foul release surfaces is significantly lower than this for tin-free SPC surfaces, when similarly applied. This indicates that at the same stream wise Reynolds number the ratio of the inner layer to the outer layer is smaller than that for foul-release surfaces [Candries M. , 2003].

9. Conclusions

The presence of organotin compounds which act as biocides in antifouling systems on ships, should be completely prohibited by January, 1st 2008.

Hull roughness must be kept at approximately the level of below 250 microns, by the application of best practice hull maintenances and antifouling coating.

The condition and type of the paint system can have a major influence on hull roughness and ship performance. Consequently, it is often of interest for a ship operator to monitor the condition of the underwater hull via indocking and outdocking average hull roughness (AHR) surveys.

For a ten-year old ship, typically docked twice, this gives an additional roughness of 60 microns. Such a roughness increase implies an increase in power demand to maintain a speed of 3-4%. Thus, it is proper to set the saving potential by perfect hull maintenance to more than the 3-4% given by the 60 microns roughness increase.

The world-wide annual fuel increases due to an assumed fouling protection deficiency to ~ 16.5 million tons. This represents approximately 5 % of the annual sales of fuel to international shipping, leading to increased air pollution by an extra ~ 0.5 million tons of CO2.

A fouled hull causes a series of risk of transporting unwanted organisms into sensitive ecosystem.

Foul release coatings on the underwater hulls and propellers of ships are a revolutionary new way to improve efficiency. They not only provide improved environmental control, since they do not use biocides to prevent fouling, but they have also been proven to provide better fouling control than SPC antifouling. These result in increased fuel efficiency, reduced engine spare parts and reduced maintenance costs.

The addition of oil to a PDMS coating further decreases the adhesion of barnacles and certain species of oysters. The environmental impact of these coatings is minimal since oil does not significantly deplete from the coating.

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