CONTROL OF BIOCORROSION TO PREVENT THE PROPAGATION OF INVASIVE SPECIES

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Biocorrosion or biofouling on ships hull occursdue to the attachment of barnacles, mollusks and other aquatic organisms on the surface of ships which leads to increase in fuel consumption, reduction of the vessels speed, premature failure of the hull, etc. Recent developments in antifouling paints, in general, prevent fouling in about 95% percent of the vessels underwater surface, which ship operators find satisfactory as far as the routine vessel operation is concerned. However, this is not sufficient to prevent the transport or invasion of alien species. In recent years the issue of invasive marine species has been receiving considerable attention due to the fact that introduction of nonidegenous species or non-native species transmigrated from other areas to coastal waters often results in the reduction and even extinction of the native species and thereby severely disrupting the natural marine ecosystems. The predominant vector for the transport of nonindigenous species in marine environments has been shipping. While ballast water receives the most attention, hull fouling is now considered to be the most significant means for translocation of these organisms. For example, 90 percent of the 343 marine alien species in Hawaii are thought to have arrived through hull fouling. Certain niche areas of the vessel such as bow thrusters, sea chest, stern tube, rudder etc. are the likely areas to be heavily fouled. In addition, the other areas that are likely to be fouled are on locations where antifouling paint has been worn of due to excessive shear and bending of the hull. This paper reviews the various antifouling strategies and aims identify areas on the hull surfaces of certain classes of vessels that are prone to fouling by excessive shear and bending and identify suitable antifouling treatments to further reduce the risk of transportation of alien species.

INTRODUCTION

Prevention of fouling on ships hulls has long been a priority for ship owners and operators because of the negative impact fouling has on the economy and performance of a vessel. Hull fouling reduces vessel speed, increases fuel costs and imposes time and costs for hull maintenance. Antifouling paints that are designed to continuously leach biocides at the paint/seawater interface are the predominant means of controlling fouling for a vast majority of the vessels. Over a period of years in the latter part of the last century there has been a marked improvement in the effective life of antifouling paints. In the 1920's ships were docked every 6 to 8 months by which time they were heavily fouled (Visscner, 1928). In the 1960's the average docking period had extended to 12 months (Skerman, 1960). It was in the 1970's after the development of Tributyl tin

(TBT) based self polishing paints (SPC) that the dry-dock periods have been extended to five years. However, TBT based paints have been phased out due to environmental concerns and have now been replaced by tin-free paints. Tin-free antifouling paints although are not as effective as their tin-based counterparts are generally satisfactory in the control of fouling as far as routine operation of the vessel is concerned. However, even the best maintained vessels are fouled to the extent of at least five percent of the total surface area. This fouled area, although a small fraction of the entire vessel surface, is the primary vector for transmigration of invasive species.

INVASIVE SPECIES

Ranges of species fluctuate naturally on a time scale of centuries to years as a result of alterations in climate or biological interactions. Thus, an alien (also known as exotic, introduced, invasive, non-indigenous, non-native) species is any species intentionally or accidentally transported and released by man into a habitat outside its native geographical range: otherwise it could not be able to overcome environmental barriers (ocean waters, land masses) separating its region of origin from new locale. These human- mediated invasions, often referred as biological pollution, represent a growing problem due to the unexpected and unwanted impacts the nuisance species might cause to the environment, economy and human health. Effects of alien species on marine environment and native biodiversity are numerous. They include changes in resource competition (food, space, spawning areas); physical changes in habitat (reduced water movement, biogenic erosion of shores, alteration of bottom substrate); limitation of resources (nutrients, light, oxygen); detrimental changes in the tropic web due to introduction of a new functional group; harmful algal blooms; genetic effects on native species (hybridization, change in gene pool, loss of native genotypes); drastic reduction of the population size or even extinction of native species (Minichin and Sides, 2006). Environmental changes induced by biological invasions often also cause economic impacts as well,. For instance: invasive alien species can compete with and reduce commercial fish stocks; toxic blooms can affect aquaculture, erosion of shores can harm coastal installations. Invasive species may also directly effect: water abstraction (clogging of water intake pipes); aquatic transport (fouling of boats, buoys etc., including costs of cleaning and antifouling painting, which, in turn, harms the environment); tourism (massive accumulation on shores causing smell, discoloring of water, sharp shells); fisheries (clogging and fouling of fishing gears, damage of catches in nets); aquaculture (fouling of lines, cages, cultured mollusks, fish kills, etc.) as well as human health (newly brought infections, toxins in wild-harvested fish and shellfish, new intermediate hosts for human parasites, etc.). The United Nations Environment Programme (UNEP) and World Conservation Union (IUCN) announced at the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002, that invasive species are the second greatest threat to global bio-diversity after habitat loss. Alien aquatic species are mostly transported intentionally for stocking and aquaculture purposes or unintentionally with interregional and intercontinental shipping. The importance of ship transportation in the spread of invasive species has increased tremendously in recent time primarily due to the fact that there has been a large increase in shipping traffic as well as an average increase in vessel speed, thereby increasing the chances of survivability on the transported organisms. Vessels provide habitats for a large variety of organisms, from viruses and microorganisms to various plants and animals, due to their transport of ballast water, sediments in tanks and hull fouling.

ANTIFOULING PAINTS

The use of antifouling paints is the predominant technique to control hull fouling. The various types of AF paints are widely used in the shipping industry are briefly discussed next A comprehensive review of Antifouling paints is given by Chambers *et al* (2006) and Yebra *et al* (2004)

Insoluble Matrix Antifouling Paints These paints are also called diffusion or insoluble matrix coatings, are based on insoluble resins such as chlorinated rubber, vinyl, or acrylic groups. In these types of paints, only the biocides are leached out leaving behind a porous paint film skeleton and as the thickness of the porous layer increases, the leaching rate of the biocide is reduced. The paint skeleton remaining after the leaching process is over is relatively weak, making re-coating with fresh paint difficult. The effective life of these paints is about 12 months.

Soluble Matrix Antifouling paints In the conventional free association paints, the biocide is physically dispersed and subsequently released from the paint matrix. Sea water penetrates into the paint film and leaches out the biocide. The water-soluble biocides are typically dispersed in a slightly soluble matrix usually made of resin, plasticizers, or synthetic polymers. The life span of these paints is usually between 12 and 18 months. In the eroding/ablative or controlled depletion polymer coatings, in addition to the leaching of the biocide, the paint matrix is continually worn of by a dissolution/erosion process which increases the leaching rate of the biocide. The most common biocide used in these paints is copper either as a metal or as a compound. To improve the efficiency, booster biocides are frequently incorporated into the paint matrix. The AF performance of these paints is reported to be approximately 30 months.

Self-polishing copolymer To reduce the leaching rate of the biocide and to increase the efficacy of the paints, self-polishing (SPC) paints were introduced in the mid-1970s. In this class of paints, the biocide is chemically bonded to a copolymer. The leaching rate of the biocide is highly controlled due to the fact that biocide is released when sea water reacts with the surface layer of the paint. The SPC paints allow the application of thicker coatings with the biocide chemically bonded throughout the coating. This results in the slow and uniform release of biocides to the surface. The biocide release for these coatings is only a few nanometres deep and the spent layer is slowly eroded away and a new active layer develops. SPC coatings are the most widely used antifouling paints in the shipping industry. The popularity of these AF coatings was primarily due to a controlled chemical dissolution of the paint film capable of long dry-dock intervals, typically between five to seven years; predictable polishing, enabling tailor-made specifications by vessel/operation; thin leached layers, making it easy to clean and recoat; good weatherability, quick drying, and extremely good value for money.

Biocide-free eroding coatings These coatings are very similar to SPC paints except that they contain no biocides in their formulations. The self-polishing characteristics are due to a controlled hydrolysis mechanism. These paints are primarily used in recreational vessels in areas where the use of biocides is completely banned such as protected lakes and other water bodies.

Non-stick coatings Most non-stick coatings use PDMS (polydimethylsiloxane) as the backbone polymer and are familiarly known as silicone based paints. The characteristics of these paints are that they possess a very low surface energy for the attachment of marine organisms. In addition, they are hydrophobic, flexible, possess low surface micro roughness, and are biocide free. Marine organisms that do attach on the surfaces coated with these paints are easily removed by shear forces due to the movement of the vessel, by low pressure water wash in dry-docks. They can also be easily by underwater divers which is an attractive feature since ship owners save time and money by avoiding dry-docking.

PERFORMANCE OF ANTIFOULING PAINTS

Insoluble matrix and soluble matrix antifouling paints are seldom used in the commercial shipping industry due to their short life span and thereby resulting in more frequent dry-dock intervals. However, due to their low cost they are predominantly used in the boating and pleasure craft industry.

The most frequently employed AF paints in the shipping industry are the self polishing paints (SPC). The extent of polishing action in these coatings depends on the hydrodynamic forces at the paint-seawater interface. The higher the hydrodynamic forces, the higher are the polishing rates. Certain areas of the vessel such as the bow, stern, etc experience greater hydrodynamic forces and therefore higher polishing rates thereby resulting in premature fouling. Conversely, areas where the flow rates are considerably smaller would experience lesser polishing rates which would result in insufficient amount of biocides being delivered which would again result in premature fouling. The current painting practice is that an antifouling coating of uniform thickness is applied without taking into considerations of the various hydrodynamic forces involved. Although this painting practice provides foul free hulls to an extent of up to ninety five percent, severe fouling is observed in areas where there are large variations in the hydrodynamic forces.

For non-stick coatings to be effective, the vessel must maintain a minimum average speed, typically above 20 knots, in order that fouling organisms that attach on the hull are sheared off. These coatings are therefore limited to high speed vessels, high activity vessels such as passenger ships, Ro-Ro vessels, naval ships, gas tankers and other high speed craft. In addition, these coatings are expensive, difficult to apply and can be easily prone to mechanical damage. Although the recently introduced fluoropolymer based non-stick coatings alleviate some of these problems, they are still limited in use to a certain class of high speed and high activity vessels.

Biocide free self-polishing coatings offer limited antifouling protection and are primarily applied to pleasure boats that ply in areas where the use of biocides is banned by local authorities

HULL FOULING AS A VECTOR FOR TRANSPORT OF NON-NATIVE SPECIES

Currently available antifouling coatings, in general, offer sufficient antifouling protection as far as routine vessel operations are concerned. Most of the vessel’s hull is foul free and the vessels are able to maintain their rated speed and avoid excessive fuel consumption. Yet this hull protection is not sufficient, in most cases, to result in totally clean hulls. The cleanest hulls can have up to five percent of their underwater areas fouled and cause fouling organisms to migrate along with the vessel to areas that are alien to its natural environment where they eventually propagate and grow (Ashton *et al*, 2006, Drake and Lodge, 2007).

Short effective lives soluble and insoluble matrix paints tend to cause vessels coated with these paints to be quickly fouled. Typically, these coatings are widely used in the boating and pleasure craft industry. Most often, fouling organisms migrate to alien locations when the boats are transported from one region to another overland. Although most local regulations require that when these crafts are transported overland, their hulls must be scraped to be foul free, it is often difficult to regulate these controls.

In case of vessels coated with biocide based self polishing antifouling paints, wide variations in local velocity profiles lead to excessive polishing of the antifouling coating in some areas and insufficient polishing in other areas that eventually leads to fouling in both these locations. Another critical area that deserves attention is paint failure due to bending of the vessel under loading. As can be seen in Figure 1, the deflections of a vessels plate are in the order of 5000 microns, whereas paint thicknesses are in the order of 250 microns. Such deflections would lead to paint failure at the point of inflexion and would again result in premature fouling.

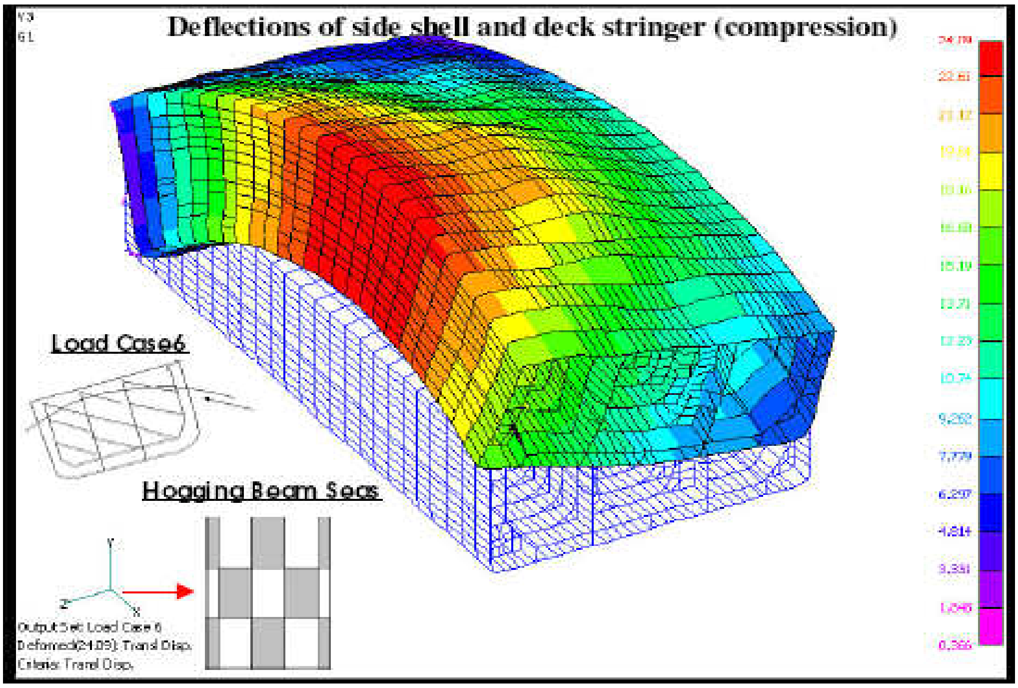

Figure 1. Deflection of vessel plate due to loading

Non-stick coatings, in the recent past, are gaining popularity due to the fact that they do not release biocides to the aquatic environment and are considered “eco friendly”. However, these coatings are totally not “non-stick” or foul-free. Fouling organisms do attach on the hull surfaces when the vessel is stationary while anchored in ports of call. These attached organisms are sheared away from the surface when the ship is in motion at higher speeds. A fraction of the organisms that append to the hull may not be sheared away and migrate to next port of call. Also, these vessels are frequently cleaned by underwater divers which results in contamination with alien species with the local organisms.

STRATEGIES TO CONTROL HULL FOULING TO LIMIT THE TRANSMIGRATION OF INVASIVE SPECIES

As there is increasing evidence that relatively small areas of ships, boats, etc, that are fouled, are primarily responsible for exponential growth of exotic species in alien environments, it is imperative that hulls of vessels must be protected from fouling not only to reduce the drag on the vessel but also to limit the proliferation of alien species (Gonzales and Johnson, 2005). Regulations are in place in many countries to ensure that vessels are essentially foul-free, but for the moment, these controls are applicable to the boating and pleasure craft industry only. Although most of these regulations stipulate that boats arriving overland must be completely foul-free, enforcement of these regulations are quite often lax, particularly in developing countries. Strict enforcement of these regulations is essential before there is irrevocable damage to the native environment.

The commercial shipping industry is far more responsible for this problem, yet there are no controls on this industry as far as *any fouling* is concerned. Ship owners and operators pay scant attention to fouling in niche areas of the vessel as it marginally affects the overall economics of maritime trade. However, as this issue has far reaching consequences, the areas of the vessel that are prone to fouling must be particularly addressed. A hydrodynamic analysis of fluid flow around the vessel, which is routinely done in the design stage of the ship, provides valuable information on the velocity profiles around the ships hull. This data could then be correlated to polishing rates for vessels that are coated with self polishing paints. Areas that have extremely high or low hydrodynamic forces could then by identified and suitable paint formulations/schemes could be applied at these niche locations. Similarly, a stress analysis of the vessel under loading (which is also done at the design stage), provides data on the bending characteristics of the ship. Paint film rupture points/locations could be identified and paints with suitable elastic properties could be formulated for application at these locations

For vessels coated with non-stick coatings, hull cleaning of the vessels must be regulated, particularly in-water hull cleaning. Few countries such as Australia and New Zealand have already placed strict controls on in-water hull cleaning and other countries are likely to follow. Typically, this washing could be carried out in dry docks and the washed material could be treated before disposal in to the aquatic environment.

Finally, hull husbandry schedule is to be strictly maintained. Hulls should be recoated with antifouling paints as per the manufacturer's recommendations and antifouling regimes as per the vessels speed and activity are to be diligently followed.

CONCLUSIONS

In recent years, there has been an exponential rise in the populations of non-native species. There has been increasing evidence that hull fouling is the predominant vector for the transportation of these species. Antifouling paints applied on ships ensure foul free hulls up to a maximum of ninety five percent of the underwater area. While this protection is satisfactory for the routine operation of the vessel, it is responsible for the wide spread propagation of non-native species. Niche areas of the vessel such as the bow, stern, rudder, sea chest and the hull exposed to non-uniform flow rates and stresses are the most prone to biofouling. Special paint regimes in these areas along with planned hull husbandry are essential to control the propagation of non-native species.

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