FAILURE ANALYSIS OF ANTIFOULING PAINTS ON SHIPS HULL

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Abstract

Fouling on ships hull occurs due to the attachment of barnacles, mollusks and other aquatic organisms on the underwater area of Ships hulls. This leads to increase in fuel consumption, reduction in speed, unscheduled dry-docking, premature failure of the hull etc. Recent advances in antifouling (AF) paints, in general, prevent fouling in about 95 % of the vessels immersed surface. However, the remaining area which amounts to 5% or less of the total area does get fouled. Although this level of fouling has marginal impact on the routine performance of the vessel, it is a predominant vector for the transmigration of invasive species which is a serious environmental concern. Invasive or alien species propagate and grow in their new environment and compete with the native species for food and other resource and thereby seriously disrupting the food chain and the natural ecosystem. Virtually all ocean going vessels are coated with antifouling paints, predominant among them are "Self polishing coatings". These coatings depend on hull shear forces caused by the motion of the vessel for the paint to "polish" away and release a biocide at a predetermined rate that results in the hull to be essentially foul-free. Currently hulls are coated with a uniform layer of antifouling paints. However, Computational Fluid Dynamics (CFD) analysis conducted on various types of vessels have indicated that there are certain "hotspots" where shear stresses and therefore the polishing rates are exceedingly high which would polish the AF paints at a much faster rate and ultimately result in the failure of the AF coating. The analysis also indicates that these hotspots primarily depend on the profile of the vessels, its speed and its draft. The current practice of a uniform coat of AF paint does not take into account the fact that there are certain areas of the vessel where the polishing rates are excessive. A possible solution to this issue is to first identify these hotspots and suitable paint schemes/formulations are to be applied in these areas. Such painting schemes would prevent the premature failure of the AF coating in general and significantly reduce the risk of transmigration of invasive species.

Key words: Biofouling, Antifouling, Niche areas, Paint scheme.

Introduction

Prevention of fouling on ships hulls has long been a priority for ship owners and operators because of the negative impact it 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 (Townsin, 2003). The use of biocide based antifouling paints are the most economical method to control hull fouling (Hare, 2000). Biocide based antifouling paints that are continuously designed to leach biocides at the paint/seawater interface are the predominant means of controlling fouling for a vast majority of the vessels. Recent advances in antifouling paint technology have led to the development in highly effective antifouling paints which generally result in foul free hulls for periods ranging from three to five years. 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 and does not affect the general performance of the vessel, is the primary vector for transmigration of invasive species, which is a serious environmental issue and immediate measures to address this issue are imperative in order to prevent major and possibly irreversible damage to the marine ecosystem (Drake and Lodge, 2007).

Invasive Species

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 (Minchin and Sides, 2003).

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.

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 affect 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.). Together, bioinvasions and habitat destruction have been major causes of species extinctions throughout the world in the past few hundred years. Aquatic invasive species can have significant undesirable impacts on ecosystems by causing a loss of biodiversity. This irretrievable loss of biodiversity is one of the ecological costs of biological invasions.

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 next only to 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 (Cohen & Carlton, 1995, Eno *et al*, 1995). 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. Earlier Ballast water as the pathway that has been the major focus of investigation as a marine invasion vector, and biofouling that occurs on the surfaces of vessel hulls as been given less attention.

Recent studies suggest that fouling growth on vessel hulls is a significant vector for invasive species, possibly equal to ballast water (Cranefield *et al* 1998, Tresher *et al*, 1999, Hewitt, 2002, Gollasch, 2002, Coutts, 2003, Minchin *et al*. 2003, Savareses, 2005, Mineu *et al,* 2007*,* Piola et al. 2009, Davidson *et al*, 2009, Sylvester *et al*, 2010). In fact 70% of all established NIS introductions to coastal N. America (Fofonoff et al. 2003) and 75 % in Australia (Hewitt *et al*, 2004) may have been fouling-mediated.

Antifouling Paints

Until the mid 20th century, the effective life of antifouling (AF) paints was approximately six months and dry-docking twice a year was not uncommon for a vessel to have its hull cleaned followed by a fresh coat of AF paint. In the late nineteen sixty's TBT based "self-polishing" (SPC) AF paints were introduced that had an effective life of more than five years. TBT based SPC coatings were unique in that there was a controlled release of biocide (TBT) by the "polishing action" of hydrodynamic forces caused by the relative movement of the vessel and the adjoining fluid which resulted in exposing a fresh layer of paint. Biocide released from the paints was extremely effective in controlling all types of fouling. Another advantage with SPC coatings is that they could be tailor made to suit various environments – for example low speed, low activity vessels could be coated with “softer coatings” to ensure high biocide delivery while high speed, high activity vessels would typically have “harder coatings”.

Beginning in the 1980’s serious environmental concerns were raised on the use of TBT based AF coatings and it was described as the most toxic substance ever introduced in to the marine environment. This resulted in an IMO led ban which prohibited the use of all organotin based paints on vessel’s hull. The paint industry responded to this ban by introducing other forms on AF coatings, the foremost among these are copper based AF SPC paints. There are doubts that the copper based AF coatings are not as effective as their TBT counterparts. Also, restrictions on the use of copper due to its deleterious environmental effects are beginning to appear in some countries. A recent development in AF paints is the introduction of “foul release coatings”. Fouling release coatings do not prevent fouling by release of a biocide, but instead have low energy surfaces that minimise the strength of adhesion of attaching organisms. Most of the fouling organisms that do attach under static conditions are sheared away once the vessel moves. The inherent draw backs of these coatings are that they are very expensive, have a difficult application procedure, they are easily damaged by mechanical forces and are effective at vessel speeds in excess of 20 knots (Hopkins and Forest, 2008). An excellent review of commercially available antifouling paints is given by Yebra *et al.*(2004).

A majority of the worlds shipping fleet is coated with copper based AF SPC primarily due its reasonable cost and efficacy as compared with other AF formulations. The usual practice is that a predetermined uniform layer of coating is applied through out the vessel depending on the average speed and activity of the vessel, although in recent times paint manufacturers are advising vessel owners to apply a different formulation to the vessel’s bottom. The structural diversity of the vessel provides a complex range of shapes ranging from near vertical at the sides at the waterline to horizontal at the bottom and varying shapes in between. In addition, there are various protrusions and recesses such as rudders, propellers, bow thrusters, sea chests, etc. The net effect is that fluid flow around the submerged hull is far from uniform and it is expected that non-uniform hydrodynamic forces at the fluid hull interface would be the result.

Regulatory Regime

The Marine Environmental Protection Committee (MEPC) has recently issued guidelines (MEPC 66, 2014) for controlling biofouling as listed below

These guidelines are based upon the following principles:

- The risks posed by biofouling management measures should be balanced with the risks of failing to manage biofouling.

- There is an operational need to manage biofouling on vessels and movable structures.
- It is preferable to minimise the accumulation of biofouling on vessels and movable structures.
- It is preferable for biofouling to be removed in the location where it was acquired before departing or moving to a new location.
- Release of potentially toxic chemicals and invasive aquatic species into the environment should be minimised.
- Where operationally and economically practicable, vessels and movable structures should be removed from the water for cleaning and maintenance, in preference to in-water operations.

The above guidelines emphasize that it is preferable to conduct "in water" cleaning prior to departure from port. However, in water cleaning is, in general, is a difficult and laborious procedure and could potentially damage the protective AF coating which in turn would accelerate the fouling process. A better approach to this problem is to prevent incipient fouling by coating the hull with the requisite paint film thickness.

Analysis of Hydrodynamic Forces at Fluid Hull Interface

A CFD analysis of the hydrodynamic forces around the hull of a tanker and a 100 passenger vessel was conducted using FLUENT software. Figures 1 and 2 shows the wall shear stresses of a 200 meter long tanker figures 3 and 4 show the computed stresses of a 100 passenger vessel operated by the Andaman and Nicobar administration. In all the figures shown below there is a marked variation in the wall shear stresses throughout the hull, which depends on the speed, the draft and the vessel profile. Certain areas of the vessel experience higher hydrodynamic forces and therefore higher polishing rates thereby resulting in premature fouling. Conversely, areas where the forces 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. For both the tanker and the 100 passenger (PAX) vessel, the computed shear stresses at the waterline and the stern have lower than average hydrodynamic forces which indicates low polishing rates, the extent of which depends on the draft, speed and type of vessel. In these areas insufficient biocide delivery results which is likely to result in premature fouling. On the other hand, for the tanker in particular, the shoulder of the vessel (below the bow) experiences high wall stresses which result in higher polishing rates in comparison to the rest of the vessel. This would lead to the premature depletion of the antifouling paint and would again result in fouling much ahead of the bulk of the surface of the vessel.

Conclusions

The results of the simulation conducted indicate that due to non-uniform shear stresses, there is likely to be uneven polishing of SPC coatings around the ships hull. This could result in AF protection at the regions of high wall shear stress particularly towards the end of the dry-dock cycle. Fouling could build up to 150 kgs per square meter within six months for an unprotected hull. For example for a large tanker whose under water surface area is in the range of 20,000 m^2, and even if one percent of the area is depleted of AF coating, it could lead up to approximately three tons of fouling material. Although this large build up of fouling organisms is not likely to effect the routine operation of the vessel, it is a substantial propagule pressure for the propagation of unwanted species in an alien environment. Therefore it is highly advisable to identify regions around vessel's hull that are prone to high wall stresses (which in turn would lead to AF coating failure) and suitable paint schemes must be applied at these locations.

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References

1. Anderson, C.D., Self-polishing Antifoulings, A Scientific Perspective. In, Proceedings, *Ship Repair & Conversion,* London, (November 1993) 1 - 17.
2. Anderson C., Coatings, Antifoulings, *Kirtk - Othmer Encyclopedia of Chemical Technology*. 7(2000) 150-167.
3. Baier, R.E. and Meyer A.E., Surface Analysis of Fouling-Resistant Marine Coatings, *In, Thompson,* M.-F., Nagabhushanam, R., Sarojini, R. and Fingerman, M. (eds.), *Recent Developments in Biofouling Control.* A.A. Balkema, Rotterdam. (1994) 285-304.
4. Callow, M.E., Ship-fouling, The Problem and Methods of Control, Biodeterioration *Abstracts 10* (1996) 411- 421.
5. Cohen A.N and J.T Carlton, Nonidigenous aquatic species in a United States estuary, A case study of biological invasions of the San Fransisco bay and Delta, *A Report For The United States Fish And Wild Life Service And The National Sea Grant Program* [NTIS PB96-166525](1995)
6. Coutts, A.D.M., K.M. Moore, and C.L. Hewitt, Ships' Sea Chests, An Overlooked Transfer Mechanism for Non-Indigenous Specie, *Marine Pollution Bulletin* 46 (2003) 1504-1515.
7. Cranfield, H.J., D.J. Gordon, R.C. Willan, B.C. Marshall, C.N. Battershill, M.P. Francis, W.A.Nelson, C.J. Glasby, and G.B. Read, *Adventive marine species*, National Institute of

Water and Atmospheric Research, Wellington, New Zealand 1998, Technical Report (34), pp. 48

8. Davidson I.C., Brown C.W., Sytsma M.D., Ruiz, G.M.,. The Role of Containerships As Transfer Mechanisms Of Marine Biofouling Species. *Biofouling* 25 (7) (2009), 645–655

9. Drake J.M., and Lodge D.M., Hull Fouling Is A Risk Factor For Intercontinental Species Exchange In Aquatic Ecosystems, *Aquatic Invasions*, 2, 2(2007) 121-131.

10. Gollasch S., The Importance of Ship Hull Fouling as a Vector of Species Introductions Into The North Sea, *Biofouling* 18(2) (2002) 105-121.

11. Eno N.C., Clarke R.A and Sanderson W.G., Marine species in British waters, a review and directory, *Joint nature conservation committee*, Peterborough, UK (1997).

12. Hare, C.H., Marine Fouling and Coatings for Its Control. J. Prot., Coating, Lining 176(2000) 47-48.

13. "*Hopkins G.A, Forrest B.M., Management options for vessel hull fouling: an overview of risks posed by in-water cleaning" – ICES Journal of Marine Science*, 65(2008) 811–815.

14. Fofonoff P.W., Ruiz G.M., Steves B. and Carlton J.T., Mechanisms of Transfer and Invasion for Non-Native Species to The Coasts of North America. In Invasive species: vectors and management strategies (ed. G. M. Ruiz & J. T. Carlton), 2003, pp. 152–182. *Washington, DC, Island Press*. Galil B.S., A sea under siege: alien species (2000).

15. Hewitt C.L., The Distribution and Biodiversity of Tropical Australian Marine Bioinvasions. *Pacific Science* 56(2) (2002) 213-222.

16. Hewitt C.L., Campbell M.L., Thresher R.E., Martin R.B., Boyd S., Cohen B.F., Currie D.R., Gomon M.F., Keough M.J., Lewis J.A., Lockett M.M., Mays N., MacArthur M.A., O'Hara T.D., Poore G.C.B., Ross D.J., Storey M.J., Watson J.E., & Wilson R.S., Introduced And Cryptogenic Species In Port Philip Bay, Victoria, Australia. *Marine Biology* 144 (2004), 183-202.

17. Hunter J.E., and Cain P., Antifouling coatings in the 1990s - Environmental, Economic and Legislative Aspects. In, [IMAS 96], Shipping and the Environment- Is Compromise Inevitable. Proc., *IMarE Conf.,. The Institute of Marine Engineers*, London UK, Part 1 (1996) 61-78.

18. Kjaer E.B.,. Bioactive Materials for Antifouling Coatings, Prog. Org. Coating. 20(1992), 339-352.

19. *Marine Environmental Protection Committee*, 66th Session Agenda Item 13(2014).

20. Minchin D., and Gollasch S., Fouling and Ship's Hulls, How Changing Circumstances and Spawning Events May Result in the Spread of Exotic Species. *Biofouling* 19(2003) 111-122.

21. Minchin D. and Sides E., Appearance of a Cryptogenic Tunicate, A Didemnum Sp. Fouling Marina Pontoons And Leisure Craft In Ireland, *Aquatic Invasions,* 1,3 (2006) 143-147.

22. Mineu F., Johnson M P, Maggs C.A., Stegenga H, Hull Fouling On Commercial Ships As A Vector Of Macroalgal Introduction, *Marine Biology*, 151 (2007) 1299–1307.

23. Piola R.F., Johnston E.L., Comparing Differential Tolerance of Native and Non-Indigenous Marine Species to Metal Pollution Using Novel Assay Techniques. *Environmental Pollution,* 157 (2009) 2853–2864

24. Savareses J., National Sea Grant Law Center, Preventing and Managing Hull Fouling: International, Federal, and State Laws and Policies, *Proceedings of the 14th Biennial Coastal Zone Conference,* New Orleans, Louisiana, July 17 to 21, 2005.

25. Sylvester F., and MacIsaac H., Is Vessel Hull Fouling an Invasion Threat to the Great Lakes Diversity and Distributions, 16(1) (2010) 132-143.

26. Townsin R.L., The Ship Hull Fouling Penalty, *Biofouling*, 19(2003) 9-5.

27. Thresher R.E., Hewitt C.L., and Campbell M.L., Synthesis, Introduced and Cryptogenic Species In Port Philip Bay. In, Hewitt C.L., Campbell M.L., Thresher R.E., Martin R.B., (eds). *Marine Biological Invasions of Port Philip Bay, Victoria*. Commonwealth Scientific and Industrial Research Organization (CSIRO), Hobart, Australia. Technical Report 20 (1999) 283-295.

28. Yebra D.M., Kiil S., Dam-Johansen K., Review, Antifouling Technology - Past, Present and Future Steps Towards Efficient and Environmentally Friendly Antifouling Coatings, *Progress In Organic Coatings* 50 (2004) 75-104.

Figures:

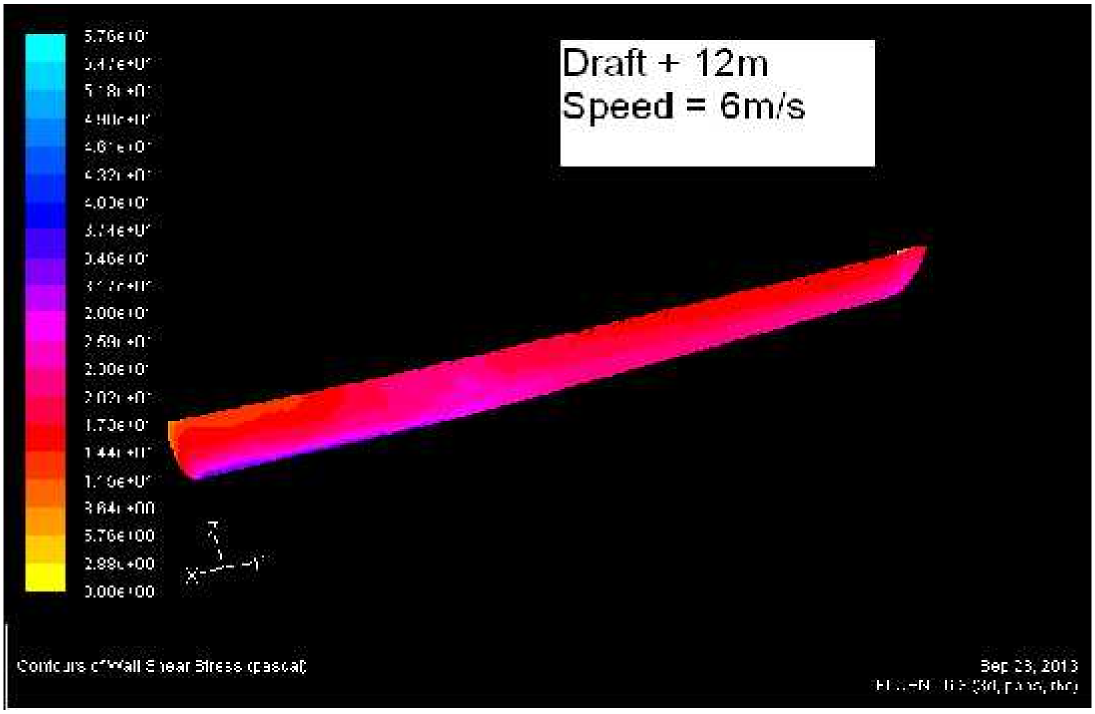

Figure 1: Wall Shear Stresses of a Tanker at a Draft Of 12 m And Speed of 6 m/s

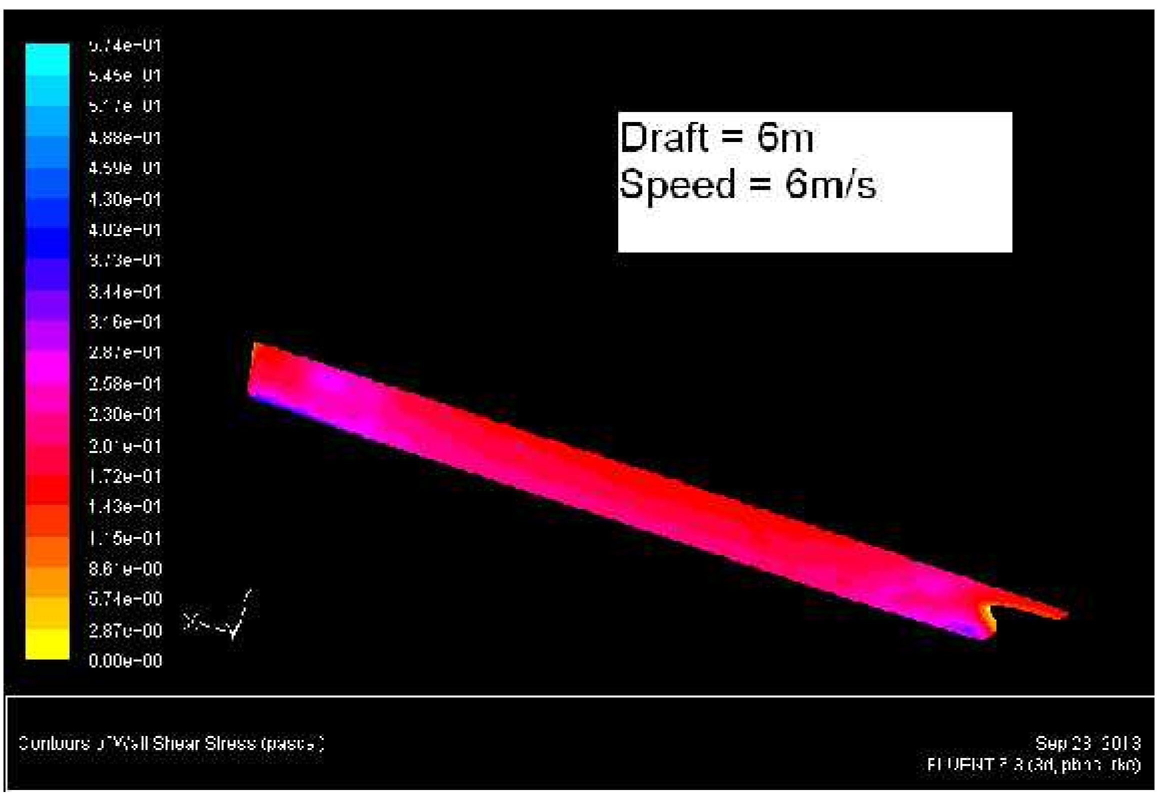

Figure 2: Wall Shear Stresses of a Tanker at a Draft Of 6 m and Speed of 6 m/s

Figure 3: Wall Shear Stresses of a 100 Passenger Vessel at a Draft of 3 m And Speed of 3 m/s

Figure 4: Wall Shear Stresses of a 100 Passenger Vessel at a Draft of 3 m and Speed of 6 m/s