Low Friction Fouling Control Coatings: An International Paint Perspective*

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Shipping is recognized as more energy efficient than many forms of transport, but increasing regulation of emissions and increasing fuel prices continue to drive the need for viable means of energy saving and reducing operational costs. One relatively easy way to do this is through the use of low friction fouling control coatings which improve the energy efficiency of ships by reducing hull roughness and frictional drag. The frictional resistance of fouling control technologies is not a new area of interest for International Paint or the marine industry. Over the years International Paint has expended considerable resources to understand the influence of coating frictional resistance on the performance and fuel efficiency of ships. Together with offering class leading products such as Intersleek® and Intersmooth®, International Paint in conjunction with BMT ARGOSSE can now deliver clarity on the fuel saving benefits of fouling control coatings in an open and transparent way with the implementation of BMT SMART^{SERVICES}.

This paper will highlight some of the advances made by International Paint and reflect on some of the current and future challenges to the marine coatings industry.

1. Introduction

The environmental impact of the world shipping fleet has been under the spotlight for some time with estimated CO₂ emissions accounting for around 3 percent of global emissions¹. According to an International Maritime Organisation (IMO) study, these emissions could grow by 150 to 250 percent by 2050 if left unregulated. To address this issue the IMO's Marine Environmental Protection Committee (at MEPC 62) have agreed a series of mandatory (Energy Efficiency Design Index (EEDI)) and voluntary (Ship Energy Efficiency Management Plan (SEEMP), Energy Efficiency Operational Index (EEOI)) energy efficiency measures to cut greenhouse gas emissions from ships.

Whilst the introduction of the EEDI is a significant step for the shipping industry, because the EEDI largely focuses on design, the use of low friction fouling control coatings have not featured. However, with the inclusion of benefits from "future technologies" the EEDI has a mechanism to incorporate the benefits of low friction coatings.

The IMO guidelines for SEEMP presented to IMO MEPC

does not give specific detail, or provide substantive information on innovations and technologies that may be employed. However, it is likely that further refinement of the SEEMP draft will call for the use of effective fouling control technologies in conjunction with regular inspection and if necessary hull cleaning.

The regulation of vessel emissions together with the general trend of increasing fuel prices adds further pressure on the shipping industry to focus on ways to control costs. One relatively easy way for ship owners/operators to reduce operational costs is through the effective use of fouling control technologies to maintain clean smooth hulls. Failure to maintain clean smooth hulls results in an increase in underwater hull roughness and frictional resistance which can lead to a significant rise in vessel operating costs.

We can characterise hull roughness in two ways: physical and biological (fouling), each with their own macro (large scale) and micro (small scale) characteristics².

- Macro physical roughness can be attributable to plate waviness, plate laps, seams and butts, welds and weld quality, mechanical damage and corrosion.
- Macro biological roughness is typically attributable to animal and weed fouling.

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- Micro physical roughness can be attributable to steel profile, minor corrosion, coating characteristics / type and condition.
- Micro biological roughness is typically attributable to biofilm/slime fouling.

The primary function of fouling control coatings is to prevent the permanent attachment of fouling organisms and by doing so limit frictional drag increase and maintain the performance and fuel economy of the ship². This can be achieved effectively through the use of either biocidal antifouling coatings such as Interspeed®, Interswift®, Intersmooth® or non-biocidal foul release coatings such as Intersleek®. It is clear that, no matter how smooth coatings are, if they cannot provide effective antifouling and/or foul release performance over the expected in-service period then the benefits offered by the underlying coating smoothness will not be fully realised.

The frictional drag penalties associated with marine fouling species and the potential impact on ship fuel economy are broadly known and explored in literature^{3,4,5}. Macro fouling species, such as barnacles, tubeworms, mussels, plant/weed species, by virtue of their size and shape can dramatically increase frictional drag and have particularly significant consequences on the fuel economy of ships. Micro forms of fouling, commonly known as biofilms or slimes, also have the potential to increase frictional drag^{6,7}. However, a general consensus on the actual magnitude of their impact is yet to emerge.

It is perhaps a reflection of improvements in the effectiveness and performance of fouling control technologies over the past few decades that attention has shifted away from the impact of macro foulers on frictional drag to focus on that of biofilms. The structure and biological make up of biofilms have been well studied and it is known that a biofilm will form rapidly on any surface immersed in sea water, regardless of whether they contain biocides or not^{8,9}. It therefore comes as no surprise that both biocidal antifouling and foul release coatings may at some point during the in-service lifetime become fully or partially covered with a biofilm. Schultz et al. provide an excellent overview of the economic impact of biofouling on a naval surface ship and conclude that light and heavy biofilms can increase the resistance up to 20%⁷. Whilst this study provides guidance on the potential impact of biofilms for navy ships, and in particular the Arleigh

Burke-class destroyer DDG-51, the conclusions from the study cannot be directly transferred to the disparate hull forms of the worldwide commercial fleet.

Secondly, but equally important, is the physical roughness and frictional drag of the fouling control coating in the absence of fouling organisms. In particular, any change in surface coating roughness during the lifetime of the coating can have a considerable impact on the frictional drag and fuel economy of the ship². Although, fouling control coatings can be carefully designed to exhibit a very smooth surface profile and low frictional drag, many aspects associated with the operation of the ship may cause an increase in the hull roughness².

2. Historical Overview

The importance of hull roughness, surface friction and the link to fuel consumption has been recognised by International Paint for many years as illustrated in this advertisement for International Compositions from 1926 (Fig 1). In fact, work published in 1904 by Holzapfel¹⁰ (original founder of International Paint) demonstrates that the link between surface friction, fuel consumption and “antifouling composition” has been a key consideration in the development of fouling control coatings for more than a century.

Fig 1, International Compositions Advertisement ca. 1926

In more recent times, two significant innovations played a key role in shaping the research programmes of International Paint: 1. the introduction of TBT based self polishing copolymer coatings in 1974; and 2. the introduction of biocide-free foul release coatings in the mid 1990's.

2.1 Self Polishing Copolymer Coatings

Following their introduction in 1974, TBT self polishing

copolymer coatings were quickly recognised as being able to deliver substantially improved antifouling performance compared with the traditional hard and rosin-based coatings then available, as well as being much smoother due to their self polishing action. At the time there was genuine technical belief that the self polishing behaviour of these coatings could deliver substantial benefits to ship owners/operators in terms of operational efficiency and fuel saving, but there was little in the way of substantive evidence to support this belief. Linking coating type, hull condition and ship performance was known to be a highly complex technical challenge requiring specialised skills and expertise. International Paint turned to the experts in marine naval architecture at the Ship Performance Group at Newcastle University for help and guidance. Over the period from 1976 to 1989, International Paint sponsored 3 research studentships conducted by Byrne¹¹, Svensen¹² and Medhurst¹³ under the supervision of Professor Robert Townsin.

The notable highlights of this work have been published in a series of papers by Townsin, Byrne, Svensen and Milne^{14,15,16,17}. The work established a direct link between the Average Hull Roughness (AHR) attributable to the coating system and ship performance. Up until this point AHR was a feature of the hull condition that was merely measured during docking. These studies provided a guide to the development of AHR with ship age and coating type. The clear benefits of a full hull blast to refresh hulls back to a lower AHR were demonstrated. Most importantly the research also found evidence that the newly introduced TBT self polishing copolymer coatings became smoother in-service and delivered ships with lower rates of increase in AHR.

Medhurst¹³ further builds on the research of Byrne and Svensen with the aim of developing a Systems Engineering approach to the measurement of the hydrodynamic and topographical properties of rough surfaces and the prediction of the frictional resistance of ships in service. Medhurst's research highlighted the complexity surrounding the measurement of surface topography, with particular reference to the influence of the techniques employed and the interpretation of the results. Medhurst successfully demonstrated that a rotating cylinder technique could be used to measure the roughness function (ΔU^+) for coatings indirectly via torque and shaft speed measurements. The rotating cylinder technique provides further evidence that

TBT self polishing copolymer coatings become smoother in-service and observed that the hydrodynamic drag of self polishing copolymer coatings always reduce as a result of the polishing phenomenon. Building on the laboratory based measurements, Medhurst demonstrated how extrapolation to full ship scale could be used as a means of predicting ship performance.

Later Townsin and Dey¹⁸ correlated the roughness and drag of a range of coated surfaces and found that the resistance of a newly painted surface correlated well with the parameter $Rt50$, which is measured on a ship hull with the BMT Hull Roughness Analyser. As a further development of these studies, Townsin developed formulae for calculating the effect of coating roughness on ship performance¹⁹.

Due to the environmental side effects associated with the use of TBT, the IMO proposed a total ban on the application of all TBT based coatings from 1st January 2003. Today's market is dominated by Tin-free self polishing copolymer coatings (e.g. Copper, Zinc, Silyl Acrylates)²⁰ which deliver comparable performance benefits to TBT self polishing copolymer coatings²¹.

2.2 Foul Release Coatings

A further major innovation in the field of fouling control coatings was the introduction of silicone based biocide-free foul release coatings by International Paint in the 1990's. This technology works by purely physical means and provides a very smooth, slippery, low friction surface which minimises settlement of fouling organisms and promotes their easy removal from the surface. The benefits offered by foul release coatings were initially realised most notably for fast moving vessels, as reported Anderson and Millet²². A fast catamaran ferry coated with foul release technology achieved a faster cruising speed, reduced journey time and lower fuel consumption when compared with the performance exhibited by the previous Controlled Depletion Polymer antifouling coating.

In order to understand and fully characterise the differences and unique benefits of foul release coatings, International Paint once again turned to the academic experts at the University of Newcastle. Working under the supervision of Professor Mehmet Atlar, Candries and then Mutton provide some very useful insights into the benefits of foul release technologies for both hull forms and propellers^{23, 24, 25}.

Candries found that foul release systems exhibited a considerably smoother surface profile with significantly lower and longer amplitude wavelength characteristics compared to that of freshly applied biocidal self polishing copolymer coatings (Fig 2). These differences in surface characteristics fundamentally affect the drag, roughness and frictional velocity.

Fig 2, Typical roughness measurement of a Foul Release coating surface (top), and a Self Polishing Copolymer coating surface (bottom)²³

This highlights one of the main limitations of the BMT Hull Roughness Analyzer, as the current equipment can only provide information relating to the mean peak to trough height over a 50 mm range (Rt50).

Candries's academic work backed up those in-service benefits observed by ship owners/operators and helped to explain why foul release coatings can provide performance benefits over other fouling control technologies.

As part of an ongoing work programme to investigate the hydrodynamic performance of foul release systems, a study into the possible benefits of their use on propellers was conducted²⁴. The benefits that this method of propeller protection offers are potential fuel savings from increased propulsive efficiency as well as lower maintenance costs and reduced environmental impact. The initial studies showed that the significant losses in efficiency caused by blade roughening can be avoided by the application of a foul release coating with a surface finish equivalent to a new or well polished propeller.

The work of Mutton et al. further investigates the potential benefits offered to propellers by foul release coatings²⁵. In particular this work focused on reviewing the feedback from ship operators of reduced noise and vibration after the application of foul release coatings. To investigate this experimentally, a series of tests using the Emerson Cavitation Tunnel at the University of Newcastle were conducted. No consistent evidence was found to indicate meaningful noise reduction, although the results did indicate some difference in noise and cavitation behaviour between the coated and uncoated condition.

2.3 Hull Roughness Penalty Calculator

Building on the close collaboration with Towsin et al. and data gathered by International Paint's Dataplan system from thousands of vessel inspections, International Paint developed a Hull Roughness Penalty Calculator (HRPC) model². This is a software system that quantifies the predicted increase in underwater hull roughness during the specified in-service period and combines this with the risk of fouling associated with different fouling control coating types.

The introduction of the HRPC meant that for the first time ship owners and operators could review the potential implications associated with fouling control coating selection as part of an overall cost benefit analysis and prediction of vessel exhaust emissions (CO₂, SO_x).

2.4 Ship Performance Monitoring and Analysis (PM&A)

In a further collaboration with the University of Newcastle under the supervision of Professor Mehmet Atlar, the work of Hasselaar explores the feasibility of developing a real-time ship performance monitoring and analysis system²⁶. The research provides an excellent review of the whole subject area and demonstrates that the design and implementation of a transparent and fully automatic, real-time, shipboard PM&A system is perfectly viable and can be installed on any ship with the use of reliable sensors.

2.5 Fluoropolymer Foul Release Technology

Since the release of the first silicone based foul release coatings, International Paint had been working to develop the next generation of coatings. This led to the introduction in 2007 of a new foul release technology, based on a unique and patented biocide-free fluoropolymer chemistry. Significantly improving upon the performance

of the best silicone based systems, the fluoropolymer system extended the use of foul release coatings to vessels operating at speeds of 10 knots and above. Further benefits in terms of lower surface roughness and lower AHR were observed (Fig 3), together with up to 50% less biofilm accumulation compared with standard silicone foul release coatings²⁷.

Fig 3, Fluoropolymer Average Hull Roughness Survey taken from a Container Vessel during dry docking

In terms of fuel efficiency and reduced emissions, the fluoropolymer technology offers, on average, a 9% improvement over biocidal self polishing copolymer coatings²⁸.

3. Current and Future Research Needs

3.1 Enhanced In-Service Performance Data

The International Paint HRP provides a useful tool to predict the in-service penalties associated with the increase in AHR and risk of fouling for each fouling control coating type. Whilst the HRP provides a future forecast of what may happen, there is no substitute for the real time collation of data from an on-board ship monitoring system such as BMT SMART^{SERVICES} 29. The collaboration between International Paint and BMT ARGOS now means ship operators are able to benefit from the availability of such data in real time.

The BMT SMART^{SERVICES} system, developed by BMT ARGOS, will capture and compile real time vessel data and simultaneously combine it with highly accurate meteorological and oceanographic data. It will record data automatically from ships' sensors to monitor engine torque, the speed log, navigational signals (heading and speed over ground), and provide performance information to the crew and to shore-based management for analysis. The system has been modelled using weighted performance coefficients

to provide the basis for measurement of vessel performance against the condition of the propeller, hull, engine and fuel consumption. In depth analysis can be used to monitor the propulsive performance of a ship and to indicate how much additional power, or fuel, would be required as a consequence of the combined effects of weather and fouling or of the isolated effects of fouling on the hull or propeller. This analysis enables data trending which can be used to optimise any scheduling of hull and propeller cleaning events and can be subsequently used to quantify the effectiveness of any such events. It is believed to be the only system that can split propeller, hull and engine factors and so accurately describe the influence of the key parameters on the changing performance of a vessel.

The BMT SMART^{SERVICES} system will deliver ship owners and operators clarity on the fuel saving benefits of fouling control coatings in an open and transparent way.

3.2 Measurement of Surface Roughness

Scientists today have access to numerous contact and non-contact laboratory based techniques that can accurately and precisely measure the surface features of coatings, e.g. stylus probe profilometers, laser profilometry, white light interferometry. Many of these techniques also allow powerful data manipulation with the ability to review numerous amplitude, textural component characteristics and produce detailed surface representations in two or three dimensions (line or 3D area scans). This laboratory-based equipment is extremely useful to coating developers who need to correlate aspects of the coating composition, rheology, application properties, etc. with the physical nature of the surface and in turn with measured frictional resistance and drag. However, a new cost effective and portable device which bridges the gap between laboratory based techniques and the BMT Hull Roughness Analyser is required to allow for more detailed measurement of the hull condition and roughness.

3.4 Impact of Biofilms on Commercial Shipping

As noted by Schultz et al.^{6,7}, a number of studies have reviewed the impact of biofilms on both laboratory scale and full ship scale performance trials, often with very different results. Although these studies provide a potential guide as to the possible performance impact of biofilms, in most of the cases the development of the biofilm does not necessarily occur in the same manner as on a commercial ship. The influence of biofilms on the roughness and

frictional drag experienced on commercial ships needs to be explored in greater detail.

4. Conclusions

For over a hundred years, International Paint has consistently been at the forefront of academic and applied research to understand the influence of coating frictional resistance on the performance and fuel efficiency of ships. This has been instrumental in the development of class leading products to control fouling and skin friction, such as Intersleek® and Intersmooth® and most recently Intercept®. This understanding continues to be refined through ongoing collaborations with key universities and industry partners such as BMT ARGOSS with the aim of delivering fuel saving benefits to customers. We look forward to helping shape the next hundred years of research in this interesting and important field.

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Questions and Answers

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Question 1: It is said that low friction antifouling coatings are difficult to evaluate because there's no fixed evaluation method so far. What are International Paint's views regarding the development of (a) a standard measurement of surface friction; and (b) the use of a standard painted panel for control / comparison?

International Paint answer:

a) The surface friction or drag of coatings can be evaluated via laboratory based approaches such as drum rotors, disc rotors, flow channels or larger scale approaches such as towing tanks and cavitation tunnels. Each approach provides different results depending on whether the surface friction of the coating is derived directly through interrogation of flow perturbations as a result of roughness elements in the viscous boundary layer, or is inferred indirectly through torque or resistance measurements. Clearly some of the methods are more practical for routine use than others. A standard laboratory method to determine the surface friction of coatings would be useful, if the measurement can be demonstrably linked to ship performance. In this respect all approaches may be valid and provide meaningful data. However, sophisticated approaches are generally required to provide more sophisticated and the most meaningful data.

b) The airless spray application of coatings is always subject to some practical difficulties which can lead to a variability in the surface roughness of the final coated article. Any variability in surface roughness will consequently result in variation of the surface friction or drag derived from the test. As such, an uncoated hydrodynamically smooth reference surface may be more reliable and easily reproduced as a standard reference / control.

Question 2: How should the performance of real ships be evaluated? What are International Paint's views regarding (a) a standard means of evaluating antifouling performance and ; (b) measurement of long term surface friction in-service.

International Paint answer:

a) International Paint regularly undertakes inspections of the underwater hull of vessels to quantify the severity and extent of fouling. The assessment protocol employed was developed by International Paint and all data collected is recorded as part of our Dataplan system. Many other coatings companies also have their own internal standards, but all are likely to be based on the same general principles for quantifying the type, severity and extent of fouling.

Both IPPIC and NACE International are working on standards to enable consistent fouling assessment. The development of an internationally recognised standard is particularly important given the growing need to inspect vessels prior to entering ports to minimise/prevent the translocation of invasive species. A new standard would help to ensure that all assessments are conducted according to the same methodology and can therefore be easily compared with other assessments. However, at the moment there is no internationally accepted definition of what constitutes a “clean hull”.

b) No practical method currently exists to directly measure the surface friction attributable to coatings on vessel hulls. However, a reliable ship Performance Monitoring and Analysis (PM&A) system such as offered by BMT SMART^{SERVICES} allows the real time datalogging of thousands of data points over time so the performance over a range of conditions can be collected and compared with the original baseline performance collected during sea trials. Although not a direct measure of the surface friction, any change in performance over time may indicate changes in the underwater hull condition, e.g. roughness increase due to damage and/ or fouling. Ultimately ship owners / operators are interested in minimising fuel costs, whilst hull skin friction is an important factor it is not the only one. A holistic PM&A system should take into account other significant variables relating to ship operations, such as trim, propeller condition, weather conditions etc.

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