Managing the underwater hull

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1. Introduction

A cursory review of major paint company web-sites, indicates claims of fuel savings anywhere in the range of 1.4 – 10% by the selection of one fouling prevention solution or another. Prima facia this provides an owner/operator significant operational cost savings, but is it really that straightforward, can such savings really be made?

The adverse effect of the ocean environment on a ship's outer bottom has been recognized over many centuries [Ref 1]:

> GRAVING is onely (used) under water - a white mixture of Tallow, Sope and Brimstone, or Train-oile, Rosin and Brimstone boiled together, is the best to preserve her calking and make her glib or slippery to passe the water, and when it is decayed by weeds, or BARNACLES; which is a kinde of fish like a long red worme (which) will eat thorow all the Plankes if she be not SHEATHED, which is as casing the Hull under water with Tar and Haire, close covered over with thin boords fast nailed to the Hull, which though the Worme pierce, shee cannot endure the Tar.

As we now know, the replacement of the 'thin boords' by copper sheathing to better resist the 'long red worme' was the precursor to the introduction of liquid paints as the predominant means of fouling prevention.

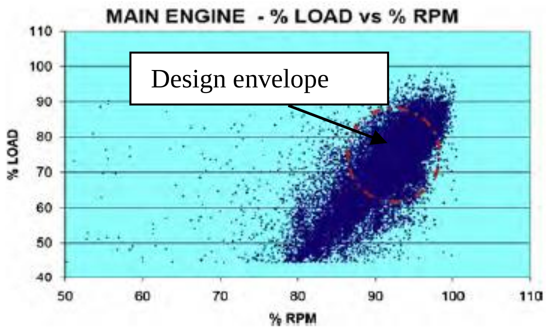
Fouling generally only takes place during static/idle periods, so the fouling prevention system needs to perform during those periods. Once the vessel is underway the frictional resistance of the hull can be important to managing fuel consumption (slime and any fouling will also have an influence).

In particular, the roughness of outer bottom coatings as applied and through life does have an impact on the rate of fouling as well as the frictional resistance of the vessel and consequently, has always been a performance concern, especially at speed/power acceptance trials.

In the 1960's and 1970's, the Ship Performance Group at Newcastle University, made considerable advances in methods for calculating the effect of hull wetted surface roughness on performance [e.g. Ref 2]. The Group's formulation for calculating the resistance penalty for a ship with a moderate and measurable roughness was subsequently adopted by the 19th ITTC in 1990. Also, in 1975, the Group developed for the British Chamber of Shipping, a standard procedure for assessing vessel speed/power performance in service at sea [Ref 3].

The overall hydrodynamic performance of a ship's hull is directly related to its resistance and propulsive efficiency. The resistance is influenced by the hull shape, appendages; the presence of thruster tunnels the design of the bulbous bow and the interaction of the hull and propeller.

Hull design has traditionally been optimised for a single operating condition of design, trim speed and draft, while increasingly vessels are operating at a range of conditions that often bear little relation to that which they were designed for as a result of changing market conditions and example of this is shown below [Ref 4]



By the 1970's the emergence of TriButyl Tin (TBT) based Self Polishing Co-Polymer (SPC) paints had appeared to resolve the issue of hull fouling and roughness, providing a predictable performance over dry-docking intervals of up to 5 years and relatively low costs when compared to the benefits obtained by the owners. Every effort was then being made to keep antifouling coatings as smooth as possible in service – to make them "glib or slippery to passé the water", while keeping the vessel foul free when static or idle.

Since then the TBT ban, increased computer processing capability and changes in the coating technology used has seen a perceived need to "re-invent" the wheel and this has mostly been undertaken by the paint suppliers. They appear to have concluded that the assessment of hull performance is a route by which they can make significant claims regarding the newer fouling prevention technologies that have been introduced and use these "results" as support to their marketing and sales initiatives.

Today, fouling prevention systems are required to perform a number of key functions:

- Asset Management
  - Meet the docking life cycle requirements, hence provide availability
- Environmental Management
  - Assist in the control of emissions from the ship
  - Prevent invasive species migration
- Commercial Management
  - Optimise fuel consumption

- Perform over a range of operations from extended port stay, slow steaming to normal operations

These functional requirements are important and are subject to increased attention from ship owners/operators and regulators.

The performance of a fouling prevention system is of main concern to the ship owner. Given that fuel consumption can account for 50% or more of vessel operating costs, then it is important for an owner to be able to predict the vessel fuel consumption costs, over the life of a charter, a voyage or dry-dock interval.

It is above all the loss of predictability since the TBT ban that has caused the most concerns. This has been voiced by a leading ship owner as follows:

For the shipyard the interest is much shorter lived, In that they are often required to design and build a vessel that needs to meet certain speed and increasingly fuel consumption targets. However their guarantee lasts 12 months and the penalties (discount in price) for not meeting these targets are trivial compared to the total through life costs that may be incurred – Jorn Kahle, AP Moller Maersk, PCE Magazine December 2013.

With fuel at $600-700 per tonne and ocean going vessels consuming anything in the range of 40 – 220 tonnes per day even a 1-2% fuel saving can provide rapid payback on any fouling prevention investment irrespective of its cost, but it has to perform and deliver the savings promised or even guaranteed from some paint suppliers.

For the paint supplier the situation is more complex. At new build their client is the shipyard, but once the vessel is in service and if they wish to retain the owner as a client, they need to consider their behaviour during the new build.

The paint supplier in general offers a 12 month guarantee to the shipyard, but increasingly are having to offer increased time frames often through the yard but in effect directly with the owner.

The standard paint guarantee allows for some fouling before a claim can be made. Typical allowances may allow up to 2.5%. While this seems a low figure, such a degree of fouling would have a serious impact on vessel performance.

2. BACKGROUND

The introduction of tri–butyl tin coatings (SPC TBT), led to the belief that fouling was 'yesterday's problem' and that Paint roughness became the predominant cause of surface resistance penalties.

The ban on TBT has led to the development of alternative technologies, still based on liquid paint, which have included both biocide based and biocide free solutions, including some that are reliant on underwater hull cleaning to prevent fouling of the hull. As evidenced by J Kahle of AP Moller/Maersk, these solutions are not performing very well and owners now seek hull management strategies to remain competitive in the prevailing market conditions, which may dominate for some time to come.

In addition to the economic penalties arising from a fouled hull, smoke stack emissions are of growing concern. Some ports and harbor authorities are becoming concerned about problems with regard to sediment contamination and issues of invasive species, which latter, are thought to arise from inadequate fouling prevention, in addition to the notorious invasion from ballast water discharge. In turn this has over a number of years tended to reduce the possibility of underwater hull cleaning, although new technologies may overcome this (see later).

Added to these is the problem of niche area fouling, where current technologies do not perform well, areas such as sea-chests and other inlets/coolers are not often well protected from fouling by current technologies.

All these circumstances have led to marine coatings manufacturers, and their ship-owning/operating customers, to pay increasing attention to the effectiveness of the various fouling prevention products on offer and their hull management options. The high cost of recoating and any subsequent economic fouling penalties, have led some paint companies to attempt to offer guarantees regarding the performance of their products, based upon some measures of speed/power performance of the ship during the inter-docking period. Such in-service data collection and analysis is notoriously difficult.

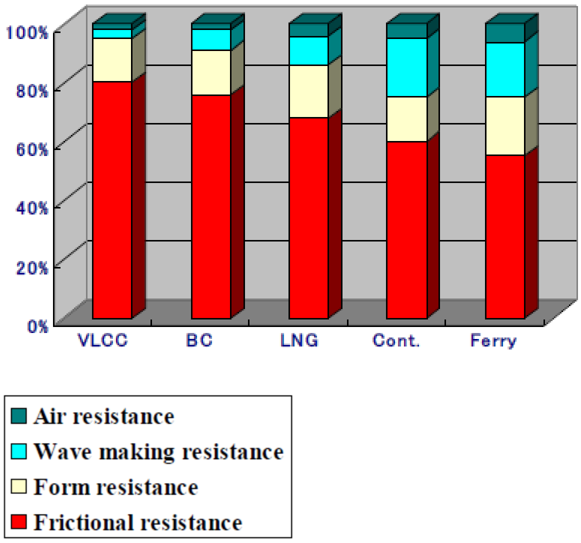
Before discussing the assessment of fouling penalties further, it is worth considering the period after out-docking and before slime and fouling first appears: It is only then that the surface roughness of the newly applied anti-fouling coating is the issue. Once slime has built up the effect of the roughness of the coating surface is masked by the presence of the slime which dominates the contribution to the frictional resistance of the hull.

The source of the problem is ultimately the resistance of the vessel through the water. This is made up of:

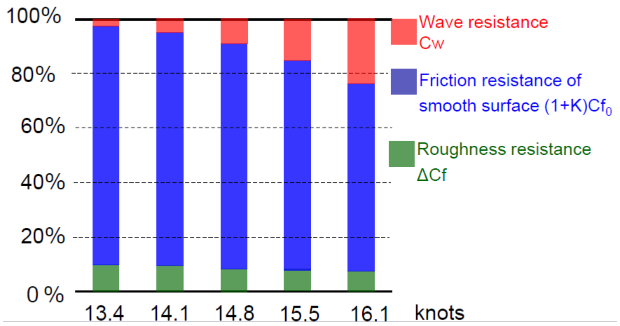
- Wave making resistance
- Frictional resistance of the smooth hull
- Roughness resistance as a result of the clean coating or the slimed/fouled coating
- Air resistance
- Appendage resistance

The key factors for the underwater hull are the first four elements. Work done in Japan Paint [Ref 5] shows the share of the contribution of these to the total resistance across a range of vessels.

While appendages are not covered in this data, it is known that poorly designed appendages can have considerable adverse effects on vessel performance e.g. thurster tunnels, bulbous bow design.



This is supplemented by work by Mieno H and Masuda H [Ref 6] that indicates that the roughness resistance of the clean coating amounts to about 7-9% of the total resistance (including the weld beads).



What should be taken away from these two figures is that the contribution of a smooth (slime and foul free) coating to hull performance is limited to about 7-9% of the total vessel resistance. It should be noted that as speed increases the wave making resistance starts to dominate the resistance when compared to roughness of the clean hull.

This is significant in that it implies that no coating could possibly offer fuel consumption improvements in excess of this 7-9%. This would seem to set some upper limit for any potential fuel savings from the application of one coating or another. On these numbers even a saving of 3.5% implies a 50% reduction in the roughness resistance of the vessel. This is not an insignificant claim, but can it be validated?

3. FUEL CONSUMPTION

Given that fuel consumption is the critical factor, it is important to note what fuel consumption of the main engine is. The specific fuel consumption of the main engine is normally determined at the shop based engine trials carried out prior to acceptance of the engine and its installation on board the vessel. This is the best indicator and is measured in gms/KW/hr. It is unlikely that any more accurate estimate of the fuel consumption of the main engine running at typically 85% MCR can be attained.

In service the engine has of course to be attached to a shaft, bearings, gearbox and a propeller. All these can only serve to adversely impact fuel consumption from the baseline data obtained in the shop trials.

The design of the propeller itself is often done in isolation to the hull rather than adopting a holistic approach and will also result in efficiencies that would serve to adversely affect fuel consumption.

The design of the hull has to be optimized. These days however most vessel designs are created by the shipyard or a design bureau working on behalf of the shipyard, the hull is often optimized for construction rather than operation, further increasing fuel consumption.

During sea trials the measured mile is used to determine if the vessel is able to achieve the contract speed and if the measured power for a range of speeds are in line with the design conditions. Though increasingly there is reference in the contract to fuel consumption, sea trial fuel consumption is measured for a specific condition, the NCR (Normal Continuous Rating) and can be subject to error when being adjusted (thus the most accurate fuel consumption figures available at that time are those from the engine trials).

Once the vessel is in service, it is unlikely that it will operate at the design conditions and hence fuel consumption would also be adversely affected as a result of wind/wave and laden condition of the vessel. Keep in mind the hull design is often optimized for the laden condition which for a number of key ship types is less than 50% of operating life.

In addition to this; if the quality of steel surface preparation (in dry-dock) and application are taken into account the sources of fuel penalties are many and varied and must all be managed.

It is also worthwhile to note that the mere process of applying paint to the outer hull will adversely affect fuel consumption because it adds weight to the vessel and generates a rougher surface than would the bare steel alone.

All these factors therefore impose a “fuel penalty” on the vessel, driving up the fuel consumption as measured at the engine shop trials.

4. FUEL SAVINGS

It is important when claims are made, with regard to fuel savings, to understand what comparison is being made. Cleary no coating can reduce the specific fuel consumption of the engine, nor make up for poor hull and propeller design or a poor operation pattern, but as long as it remains slime and foul free, the surface roughness of the coating would impact the fuel consumption in service.

Assessing the performance of a vessel at any given time, is normally referenced back to the results of vessel performance obtained at Sea Trials, this allows a comparison against base-line data as opposed to say data comparison before and after dry-docking (this does assume that the vessel condition at sea trails is an adequate reflection of her subsequent in service condition).

What this means is that the current performance of the vessel should always be assessed against the benchmark data from sea trials and the savings claimed will therefore result in a reduction of the penalty incurred against that baseline:

In assessing vessel performance two types of penalty are generally considered:

- Speed Penalty
- Fuel Penalty

A speed penalty results from an attempt to maintain specific fuel consumption when the vessel has incurred a fouling penalty. In simple terms the vessel slows down due to the increased resistance resulting from the fouling to keep fuel consumption constant.

A fuel penalty arises from the vessel being required to maintain a specific speed to meet a schedule. The incremental added resistance due to the fouling manifests itself as an increased power requirement resulting in increased fuel consumption.

In the Speed penalty, engine output is limited, while in the fuel penalty engine output is increased to maintain the speed. The Speed Penalty can also be perceived as a risk mitigation measure to avoid the thermal overloading of the main engine which could have detrimental effects.

The performance of a coating in terms of:

- Hull roughness
- Slime build up
- Fouling build up;

Can only serve to reduce any fuel penalty being incurred, thus a claim of 5-9% fuel saving applies to the penalty being incurred and not to the actual fuel consumption of the vessel/main engine. For example if the vessel at sea trials achieved a fuel consumption equivalent to 50t per day and 3 years later it was consuming 55t per day, then the fuel penalty is 5t per day and a 5% saving is 0.25t per day (i.e. 5% of 5t) after 3 years.

One final aspect of fuel consumption to be kept in mind is that of course not in all cases does the main engine fuel consumption reflect the fuel needed for vessel propulsion. Depending on the operational requirement of the vessel an additional auxiliary engine and / or auxiliary boiler might be required as well. How cargo and hotel energy demand is managed can significantly impact fuel consumption also and mask some penalties. Finally factors such as the calorific value of the fuel taken on board or the quantity of fuel loaded (how much water content?) would also affect calculations.

5. HULL ROUGHNESS PRE-FOULING.

At present there is no accepted international standard method for either measuring hull roughness or for assessing fouling. The tools available for measuring hull roughness are well established. Some authorities are proposing and developing standardized procedures for the measurement of hull roughness [Ref 7]. Such a standard procedure would be welcome to ensure the consistency and reliability upon which subsequent roughness penalty calculations depend.

The challenge in measuring hull roughness though, is two–fold; firstly a systematic and consistent method for a new hull and a repaired hull which has been blasted back to bare steel in a subsequent dry-dock and; secondly, a method for hulls that have been partially or spot blasted in subsequent dry-docks, which may serve to considerably roughen the surface. Clearly when considering a “spot blasted” or partially repaired hull the method of hull roughness measurement will need to ensure that samples taken are representative of the repaired hull surface. Of course in assessing hull roughness in this manner no fouling or slime can be present.

For information, an up-dated version of the guidance for hull roughness surveyors is provided in a recent paper by Townsin [Ref 8]. The guidance was developed by the Ship Performance Group at Newcastle University during the 147 surveys reported in [2] and the use of histograms for analysis in [9].

Many factors influence the achieved surface roughness of the hull; perhaps the most critical is not the type of coating chosen but the quality of the surface preparation of the hull and spray application of the paint. There can be a considerable difference in surface roughness between airless spray applications made at 60cm distance from the surface to that made at 40cm distance from the surface. In addition overspray can also increase roughness by up to 50µm.

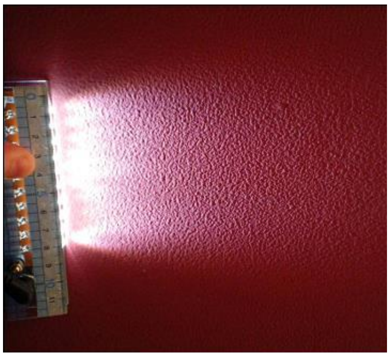


Photo courtesy of Chugoku Marine paints

Thus any coatings that purport to provide a considerably smoother finish as part of the performance benefit they offer, must be properly managed during application to assure that the benefit is realized in practice.

Of course the penalty for the freshly applied coating assumes a perfect application, while in reality there is likely to be an increase in roughness over the assumed frictional resistance of the designed hull, without any paint on it i.e. the mere process of applying a coating to the hull will increase fuel consumption. Thus this increase needs to be deducted from any claimed improvement.

6. SLIME AND FOULING ASSESSMENT.

Slime is very difficult to assess but can have considerable impact on vessel performance [Ref 10] and the submissions to the IMO would indicate that the contribution of slime to the added resistance of the vessel is much greater post TBT than it was when TBT coatings were being used.

Hull condition	Additional shaft power % increase to sustain speed
Freshly applied coating	0
Deteriorated coating or thin slime	9
Heavy slime	19
Small calcareous fouling or macro-algae	33
Medium calcareous fouling	52
Heavy calcareous fouling	82

Source: Schulz [Ref 11]

Diver reported, visual descriptions of fouling, is the predominant way of assessing the severity of slime and/ or fouling. While videos are taken to record the findings of divers and the results of subsequent cleaning it is the authors' experience that the quality and veracity of some of the videos can be questioned as well as the assessment of the extent of fouling or the quality of the cleaning process that is made from them.

7. FOULING PREVENTION TECHNOLOGY

There is a range of fouling prevention systems in the market place at present, from which an owner can choose. These can broadly be divided into the following technology groups:

- Control Depletion Co-polymers
- Self-Polishing Co-Polymers
- Foul release coatings
    - Silicone only systems
    - Silicone and biocide combinations
- Combination technologies
    - Hard coatings combined with underwater hull grooming/cleaning
    - Various coating technologies combined with ultra-sonic systems etc.

There are also a number of interesting technologies that are at various stages of development:

- Electronic systems
- Surface engineered systems
- Enzyme based systems.
- UV Light based systems

It is likely that there are others that will emerge in the coming years.

Classification societies have adopted an Eco-A notation for "green vessels" and this requires a biocide free coating application to be applied to make the vessel qualify for this notation.

The performance claims for all these technologies vary as do the various economic models that are used by the various suppliers to support the claims made in terms of in-service performance.

The reality would seem that the current technology has not yet provided either the efficacy or the predictability the industry had from the longer established TBT based systems. However, this is perhaps an unfair comparison, when TBT systems are referred to the reference points tend to be the last generation of TBT systems that were used. A comparison on this basis ignores the first 20 years or so of TBT systems in use and the gradual process of improvement that those formulations underwent over that period of time. By comparison the present solutions are relatively immature technologies and should also gradually improve in performance over time.

8. MANAGEMENT OF IN-SERVICE SPEED/POWER FOULING PENALTIES.

One purpose of in-service speed/power monitoring is to provide the ship operator with sufficient and reliable data to enable decisions to be made for the management of the underwater hull. It must be kept in mind that now all that can be controlled is the type of fouling prevention selected and any cleaning required (in or out of the water).

The ship-owner needs to decide when, where and what to do about a drop off in performance detected as a fuel penalty or a speed penalty that may result from roughening of the hull, slime build up or fouling. The action point may be voluntarily imposed or of course could be driven by charter party terms and conditions.

The options available to the operator of the vessel are then generally as follows:

- Stop the ship to carry out
    - Hull grooming; this implies a slimed hull only and hence the grooming process is less aggressive than an underwater hull clean and less likely to damage any coating. It would also require more frequent/regular intervention.
    - Partial in water cleaning (depending on the time available, the weather, the vessel condition - laden or ballast and its trim/angle of heel, as well as local port/environmental regulations) and the ability of the coating to resist the underwater hull clean without becoming rougher or being significantly depleted.
    - Full underwater hull cleaning taking into account the same issues as above. It should be noted that often once cleaned the frequency of cleaning increases as the hull tends to roughen with some coating types, encouraging fouling.
    - Operate in fouled condition until underwater hull cleaning can be carried out at a suitable location and incur the fuel consumption penalty.
- Dry-dock
    - Partial hull blasting and re-coating with existing or alternative scheme
    - Full hull blasting back to steel and re-coating with existing or alternative scheme.

The selection of the scheme at dry-dock can be fraught for a number of reasons:

1. If the existing coating has performed then the user must be satisfied that:
    a. The product formulation has not changed in the meantime as a result of regulations/legislation or value engineering.
    b. That the vessels operational profile and route is not going to be significantly different to what went before.
    c. The impact of a full or partial blast of the hull on likely performance (keeping in mind a rougher hull is more likely to foul).

2. If a new coating is to be selected, this can be done for a number of reasons
    a. Commercial offer made to entice vessel to another supplier
    b. Perceived or claimed improved performance of new product
    c. Poor performance of existing product or
    d. Poor service support from the paint company.
    e. Other commercial driver e.g. fleet contract or settlement in kind.

Other factors that should be considered if appropriate:

- For a foul release coating can the vessel achieve a suitable threshold speed to allow fouling to release from the appropriate type of foul release system
- Plan for hull cleaning by ensuring adequate DFT is applied as underwater hull cleaning can result in up to 10% (and some-times more) paint loss per cleaning.
- Operate the vessel until some form of action can be taken.
- Consider the use of dedicated on board grooming robots to maintain hull condition (has been used in offshore applications).

The key point is having the data to allow such decisions to be made/anticipated. In-service performance data collection should be of suitable quality to allow comparison with the original sea trial data and also the performance soon after dry-dock. Today, many ship owners, paint companies and other commercial organizations offer speed/power performance monitoring systems. Monitoring systems on offer vary in their approach: for example, some collect all data and correct for weather effects, some use only fair weather data. Not surprisingly, authorities are seeking a transparent, standardized method for data collection and analysis [12]. Such an outcome would be welcome to those grappling with this difficult techno-economic problem.

Ultimately the decision is based on economics and will depend upon the particular ship circumstances – ship type, trading pattern, service history etc. The two principal parameters are, of course, the power delivered to the propeller, which affects the fuel consumption, and the ship speed relative to the water just clear of the vessel. The reliable measure of power delivered will be from a shaft torsionmeter. The less reliable, but critical, parameter, is the speed through water (traditional acceptance trials measure ground speed).

Notwithstanding the best efforts to collect accurate data, it is also well understood that both the Chief Engineer and the Chief Officer on board a vessel, may keep safety margins based on their own experiences that may introduce variability to the data collected. Moreover conflicting interests between each of the Technical, Commercial and Operational stakeholders involved in the business can indirectly influence ambiguity in data quality.

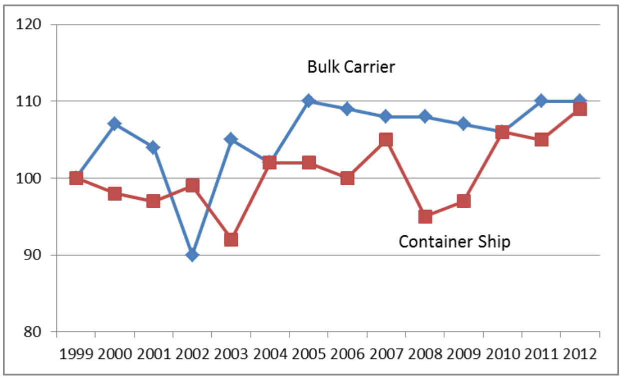
Some authorities suggest data collection only in fair weather, say BN $\leq$ 3. This allows contentious corrections for ship motions and wind to be avoided. Reference to the ISO Standard for collection and analysis of sea trial data, [Ref. 13], indicates that this can make the collection of meaningful in-service data impractical.

Unfortunately, some trading routes and seasons will not offer fair weather intervals on passage and compromises will inevitably have to be made. Weather corrections that may be made could result in a non-transparent approach to monitoring of performance.

A key factor is that of recording speed of the vessel when she is underway. This can be greatly enhanced by use of the power diagram which is the calibration of the propeller in terms of ship speed, shaft power and shaft RPM.

9. FOCUS ON SPEED AND FUEL

Fuel consumption of vessels does not appear to have significantly changed in recent years as evidenced by Stopford [Ref 14]. According to Stopford there has been no detectable improvement in fuel consumption in two key ship types, the Panamax bulk carrier and the container ship, based on the Clarkson index of fuel consumption (the higher the index the better the fuel consumption).



While the index does show a positive upward trend with the container consumption dropping from 140 tonnes per day to 136 tonnes per day over the 13 year period

Stopford pointed out that this is in stark contrast to developments in the automotive industry where during the same time period fuel consumption of the standard Ford Focus has improved by almost 44% (up from 39 miles per gallon to 56 mpg).

There is also some evidence that in the efforts to make the shipbuilding process ever more efficient some compromise has been made in terms of the hydrodynamic efficiency of the hull design (given that now many designs are developed by the shipyard itself). In addition design optimization not only has to take into account the shipyard capability and facility limits, but also port and route restrictions (beam, draft, length limiting factors e.g. Panama Canal), that can adversely affect hull hydrodynamic design.

Of course in the assessment of fuel consumption the method of measurement has to be considered. Typically this is done by reading the fuel counters once per day. However, these readings do not take into account some factors such as the fuel spilt from the fuel tank and returned to the service tanks (this could be up 3-10% depending on engine load and the use of return valves to control this). The commercial stakeholder however is more interested in the fuel remaining on board (ROB). The fuel quantities measured from these two sources rarely tally because of:

- The presence of water/sludge on board (1-2%)
- Additional sources of fuel consumption e.g. incinerator.
- Actual quantity of bunker fuel received against that ordered
- Water content of the bunker fuel.

From a Coating perspective the current focus on the analysis of fouling prevention performance is focused on the speed penalty that the vessel incurs as a result of any fouling. Thus the paint companies sometimes offer speed loss as a measure of the performance of any fouling prevention measure.

The speed penalty would be critical if vessels continued to operate close to design speeds. But on average operating laden and ballast speeds have been reduced in the recent market conditions due to increasing awareness of the relation between speed and fuel consumption.

So, speed is not the critical factor by which the performance of the fouling prevention system should be measured.

Rather, parameters like power and fuel consumption and their incremental effect due to fouling could be better indicators.

The relation between effect of fouling and speed loss could be linear as compared to an exponential relation between fouling and incremental power consumption making it complex.

Work undertaken [Ref 15] indicates that another important criterion assessed is capacity loss.

When an owner decides to acquire a ship (new or second hand) or to charter a vessel, he has in mind a route and a trade that the vessel will serve.

The vessel design will have been optimized to the design parameters which would include a design draft and a design speed. If the vessel deviates from those design parameters by loading a part cargo or reducing/increasing speed then its fuel efficiency will reduce.

Thus a key measure of vessel performance is its ability to deliver the required cargo tonne-miles per voyage as cost effectively as possible. Consider a vessel that has a design cargo capacity of 105,000 tonnes engaged on a trade-route of 5,000 nautical miles. It will have a capacity of 525,000,000 cargo tonne miles. The time in which it can deliver this capacity is dependent on the speed the vessel and dictates the earning capacity of the vessel.

If the vessel had a design speed of 14.9kts, and is chartered at 14kts and carries only 80% of its designed cargo capacity, then it would make approximately 21.46 voyages per annum of which possibly half would be in ballast based on 300 sailing days per year. Thus the vessel would deliver about 4.03 billion tonne miles of capacity per annum as compared to a designed 5.63 billion tonne miles per annum based on design capacity.

This implies a lost capacity to an owner/operator of about 28% in tonne miles per ship per annum in the difference between the design condition and the normal operating condition. If the vessel is then considered to be moderately fouled, then there would be an additional loss of about 8% in tonne miles between the operational condition and the moderately fouled hull condition. If the trade required 7 ships then the implication is that based on the design condition another 2 ships would be needed. While under the operation conditions another 1 ship would be required to deliver the same tonne mile capacity. While fouling plays an important role in the management of tonne mile capacity, the disjoint between vessel design and operational conditions can also play a critical role. This implies a need for a design approach that maximizes the operational envelope of the vessel to provide the owner/operator with some flexibility.

In terms of fuel consumption, the additional fuel consumed to maintain 14 knots speed with a 20% increase in power consumption will be about 7.4 MT / day. Or if power/fuel consumption were fixed it would result in a speed penalty reducing capacity by about 6.4%.

Thus the key issue for various stakeholders can be addressed in different ways based on the above scenario.

- Vessel availability – Up to 3 more vessels required for every 7 vessels on the as designed service.
- Ship Owners – Cargo capacity loss of 28% or Speed loss of 0.9 knots or increased fuel consumption of 7.4 MT/day in laden passage.
- Global Society – Increased emissions from 3 more vessels and from inefficient operations and the cost and environmental impact of building those vessels.

10. MANAGING THE HULL

It is clear therefore that managing the underwater hull is a critical factor for the operator in keeping the operating costs of a vessel down. With fuel accounting for upwards of 50% of total operating costs, the means of management is critical to the earning capability of the vessel. The process is generally only considered as an issue once the vessel is in service with some minor consideration being given to it at new building and that is normally based on the selection of the fouling prevention coating/system to be applied.

However the application at the new build stage will determine the vessel performance for at least the first 5 years of its life (possibly 33% or more of the time an owner will typically keep a ship) and so what happens at new building does considerably influence through life performance. The following should therefore be considered at new building:

Design of the hull

The overall efficiency of the vessel is clearly determined by the hull design and the match to the propeller. It is necessary to design them and the bulbous bow to cater for a wider range of in service conditions. This may result in a compromise for the design condition, but may return better performance in service.
The design of niche areas needs to be considered so as to minimize the “traps” for fouling.

Distortions in the hull steel structure.

Typical ship yard standards allow for distortion in the steel work of the hull in the range of ±7mm and this influences the texture of the hull as does the presence of weld seams and butts. Thus care should be taken to minimize these distortions.

Fouling prevention system selection

At present the dominant solution to fouling prevention is based on liquid coatings, other technologies are emerging such as Ultrasonic and UV light based systems but they have not yet been proven for large vessel application over the typical life of a vessel. They may however offer solutions to niche areas.

Coating selection is important not just for the fouling prevention coating but for the whole scheme, as it is the whole scheme that contributes to the overall hull roughness. There have been recent developments in controlled self-leveling coating schemes where the anti-corrosive layers and the anti-fouling layers work together to create a smoother surface overall [Ref 4 and 5]. In general from an application viewpoint the fewer the number of coats the better as this not only reduces the variability in the application but also total weight of coating applied.

Roughness of the surface preparation

The paint supplier generally recommends a required surface profile that is typically in the range of 30 – 90µm with a cleanliness of Sa2.5. The quality of this blast is therefore critical to assure that the surface is only as rough as it needs to be.

Application of the coatings

Studies by Safinah [Ref 16] and Francis [Ref 17] show that there is considerable variation in the process of coating application that can result in a range of readings for final scheme DFT from 480 - 1500µm for a scheme specification of 740µm. Thus at the macro level the application process and subsequent touch up can considerably affect the texture of the surface. The whole of the scheme therefore should be designed and selected to minimize overall roughness and the ease of application properties of each coat should be considered.

Thus considerable care needs to be taken to control both texture and roughness by proper application to avoid unnecessary over application, could control of distance from the surface and control of overspray.

Once the vessel is in service then the options available to ensure good vessel performance, should the hull slime or foul, include:

Vessel operation

Maintaining high activity levels for the vessel (minimize static periods). This can be done by controlling speed on a voyage to provide “on time “arrival at the port to meet schedule and take into account port congestion issues. In particular static periods allowed in Charter Parties are often far more generous than those allowed under paint company guarantees (typically 10-15 days) and these should be minimized. Operating the vessel to the optimal configuration she has been designed for in terms of speed, draft etc. is also critical. In addition the employment of course optimization and weather routing, can also considerably impact performance.

Propeller clean and polish

This is perhaps the cheapest option and provides prompt pay back. There had been a slight trend in applying coatings propellers with some form of fouling prevention technology, but the cost and time for cleaning are generally not prohibitive. There are two issues for propellers one is fouling and the other is calcium based deposits resulting from the ICCP system during port time, as well as fouling. Any management regime needs to deal with both. Coating applied to propellers have generally achieved mixed results and this has prevented their wider use.

Underwater hull grooming,

This is to prevent any form of build-up of either micro or macro fouling and requires regular work, typically in the order of once a month, or on departure from any port of call or during the stay if the port allows it. This could of course impact on vessel availability and voyage time/schedule but could be suitable for some ship types. The technology required needs to be better developed, ideally with a totally enclosed system, although work carried out by the ONR and others are addressing these shortfalls [18].

Underwater hull cleaning

By definition implies that fouling to some degree has taken place and the vessel has been sailing with a fuel or speed penalty, this generally results in an increase in hull roughness (except for the hard coatings) and once carried out in general results in an increased need for further hull cleaning as a result of the rougher surface. The range in quality of these services must also be taken into consideration with quality varying considerable from one contractor to another and one type of machine to another. The problems resulting from these generally fall into a number of categories:

- Time frame results in only part cleaning of the hull
- The sea conditions results in limited ability to make use specific cleaning opportunities
- The cleaning process can result either in depletion of the coating (up to 50µm or more per clean)
- The cleaning process can damage the coating and inadvertently roughen the hull
- Poor cleaning process e.g. wrong brushes or fouling not properly removed.

Thus, the decision to underwater hull clean and its likely benefits need to be carefully considered and planned to maximize the gains while minimizing the downside. It is also understood that once a hull has been cleaned it tends to foul more readily and therefore the interval between the need for cleaning diminishes, this results in increased need for cleaning and increased depletion of the coating as well as increased hull roughness.

Port berthing based services

At present the technology options are based upon coating selection, hull cleaning/grooming and or dry-docking. While not in existence there is research work being undertaken as proof of concept to investigate ways of making the berth in a port provide a service for keeping the hull clean this could comprise aeration systems [19] or UV lighting systems [20] that would both work to keep the hull clean during static periods in port. This type of solution has a real disruptive capability to replace biocide based coatings and to have a considerable impact on the issue of invasive species migration as the fouling will in effect stay at the place of origin.

Dry-docking

This is of course ultimately the most drastic measure that may be required to remove fouling and depending on vessel type can take place every 12, 30 or 60 months. The average for the world's fleet is around the 32 month mark.

It is interesting to note that there are various trials looking at the extension of dry-docking intervals to 7 years for commercial vessels and up to 12 years for some naval vessels. These extended periods will naturally test the long life performance of the coatings but also result in the hulls picking up more mechanical damage.

Once in dock the main consideration that an owner faces would seem to be how much surface preparation should be carried out or how much can be afforded from the operational budget.

Should the hull be blasted back to bare steel or should only spot blasting be carried out?

There is very little hard data that enables the benefits of each option to be assed as a spot blast is a vague term, even a slight elaboration to say a 30% spot blast is a vague term (is the 30% concentrated in one location or spread evenly over the hull?).

The general consensus is that while a full blast is ideal it can be perceived to be cost prohibitive. However in the experience of the authors there are a number of owners who now generally blast the full hull at each scheduled dry-docking as the improvement in hull roughness provides them a return in the form of fuel savings.

While a spot blast may offer greater merit by focusing on the forward one third of the vessels hull. What is critical for any spot blasting work is the feathering of the blasted edges. Work carried out under the auspices of National Shipbuilding Research Program in the USA [21] has indicated that if the surface is properly feathered then the roughness of a spot blasted hull can be brought closer to the performance of a full blast.

The best indications would seem to point to a 15% difference in performance between a spot blast and full blast. Work done by Townsin/ Byrne [Ref 9], indicated that average hull roughness increased by 45µm at dry-docking if the hull was not full blasted. Thus when considering a spot blast option, it is important to keep in mind how to minimize the impact of that on overall hull roughness.

What is also interesting to observe is that despite all the emphasis being placed on hull roughness and the merits of one type of coating over another, how few paint specifications actually specify a hull roughness value for the newly delivered ship and if specified how few times it is actually measured.

This is the same for dry-docking, where hull roughness is rarely specified and rarely measured (usually as a result of time constraints). Perhaps the introduction of standards for this will increase the demand for better designed and built vessels and enhance the operational performance in service.

Managing other on board systems

While the focus of this paper is on fuel consumption related to the underwater hull, clearly the optimization of how other energy consuming systems on board the vessel are used can also have a considerable influence on the overall fuel consumption of the vessel.

11. NON-COATING TECHNOLOGIES

Of course there are other technologies being deployed that can impact vessel performance irrespective of the coating application. These include:

Air cushions
Sails
Retro-fitting bulbous bows
Re-designing appendages
Various appendages/propeller devices

To date all of these have met with a mixed reception despite of the claims for significant potential for fuel savings made by their suppliers.

Even with the presence of these other options the overwhelming emphasis remains on the achievement of a smooth, slime and foul free hull.

12. CONCLUSIONS.

There is a considerable body of knowledge on hull vessel performance for a roughened hull but there is considerably less on slimed and fouled hulls.

The focus of the industry has generally been on how to manage the hull once the vessel is in service, but decisions and work carried out at the design and in construction can adversely impact vessel performance in at least the first 5 years of its life and potentially through life.

Data is needed in key areas such as the impact of spot blasting versus a full blast and the real cost in terms of capacity loss of practices such as underwater hull cleaning or grooming on a regular basis.

In the end it is neither speed nor fuel consumption but capacity that an owner buys when he buys a ship. The need is to deliver that capacity as cost effectively as possible and fuel consumption and consequently the performance of the underwater hull is critical to the cost effectiveness of the ship.

The TBT ban has resulted in a change to new technologies that as yet have not been able to provide the predictability that the industry had before. This has likely resulted in increased emissions and hull fouling in the short term, while the hope is that a breakthrough technology will emerge to take the industry beyond the performance levels of TBT based systems.

What is remarkable is how little information is readily available in terms of through life performance of the underwater hull. There are many case studies that compare a vessel before and after dry-docking or sister vessels over a short period of time, but no systematic analysis over the long term, say 10 -15 years is readily available in the public domain to guide further study. It is hoped that as a result of increased application of hull performance monitoring software that over time such data may become available.

The changes in technology in particular for underwater hull cleaning and the potential for technologies that may afford better use of time in port (and add revenue to the port) are likely to generate considerable disruption to the present reliance on coatings alone.

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14. AUTHOR BIOGRAPHIES

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		As Built	**Normal Operation**	**Fixing Tonne Mile / annum**	**Inversely - Fixing Power / Fuel Cons.**
		Design	**Design**	**Moderately Fouled Hull**	**Moderately Fouled Hull**
		Conditions		**20% increase in power cons.**	**6.4% reduction in Cargo Tonne Miles**
Cargo (MT)		**105000**	**80000**	**80000**	**80000**
Speed (knots)		**14.9**	**14**	**14**	**13.1**
Draft (Mts)		**14.8**	**11.9**	**11.9**	**11.9**
Sailing days		**300**	**300**	**300**	**300**
Tonne Mile / annum	**Laden**	**5632200000**	**4032000000**	**4032000000**	**3772800000**
(Assume 50% ballast)					
Engine Power (Kw)		**10950**	**7403**	**9218**	**7403**
SFOC (gms/KwHr)	**170**				
Fuel Consumption (MT / day)		**44.7**	**30.2**	**37.6**	**30.2**
			Reduction in Cargo Tonne Miles due to Speed Loss		**93.6%**