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Hull Roughness Penalty Calculator:
The economic importance of hull condition

The economic importance of underwater hull condition cannot be understated. Any increase in underwater roughness can result in a significant rise in vessel operating costs.

The IMO Convention on the Control of Harmful Anti-foulings on Ships and the subsequent debate on the performance merits of TBT-free antifouling and fouling control systems has demonstrated that the principles of hull roughness, plus the performance effects and costs of increased hull roughness on vessel operating efficiency are not widely understood.

International Paint have developed a new 'Hull Roughness Penalty Calculator'. This is a software programme that predicts the inevitable increase in underwater hull roughness during the specified in-service period and combines this with the risk of fouling associated with different antifouling types. The programme then compares vessel fuel usage and cost to the installation cost of different TBT-free antifouling and fouling control systems and calculates the exhaust emissions (CO2, SOx) associated with traditional fuel consumption.

The programme can aid the coatings selection process by comparing the predicted power and fuel increase over time for our antifoulings and fouling control systems: Intersleek 700, Intersmooth SPC, Interswift 655 and Interspeed 340.

By comparing the 'Recommended Antifouling Scheme' to the existing or 'Base Antifouling Scheme' it is possible to predict the potential fuel cost difference and potential nett benefit.

Further information about the Hull Roughness Penalty Calculator is available in this folder, including a technical paper and a CD which details the design principles on which the programme was built. If you would like a demonstration of the Hull Roughness Penalty Calculator, please contact your local International Paint Sales Executive.
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November 2004

Hull Roughness Penalty Calculator

www.international-marine.com

www.intersleek700.com

www.intersmoothSPC.com
Hull roughness penalty calculator:
The economic importance of hull condition

Introduction

The economic importance of underwater hull condition cannot be understated. Any increase in underwater hull roughness can result in a significant rise in vessel operating costs.

There are two main types of hull roughness: physical and biological (fouling), each with their own macro (large scale) and micro (small scale) characteristics.

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

Examples of how coatings condition can influence hull roughness:

![Cracking](image1)
![Detachment](image2)
![Touch-up Repairs](image3)

Any increase in underwater hull roughness will increase hull frictional resistance or vessel drag, resulting in an additional power requirement with increased fuel consumption and cost to maintain vessel speed. Conversely, maintaining constant power will result in decreased vessel speed and longer voyage times. Whilst this may appear obvious, the IMO Convention on the Control of Harmful Anti-foulings on Ships and the subsequent debate on the performance merits of TBT free antifoulings and fouling control systems has demonstrated that the principles of hull roughness, plus the performance effects and costs of increased hull roughness on vessel operating efficiency may not be widely understood.

New Model

International Paint have developed a new ‘Hull Roughness Penalty Calculator’ model. This is a software programme that predicts the inevitable increase in underwater hull roughness during the specified in service period and combines this with the risk of fouling associated with different antifouling types. The model compares fuel usage and cost to the installation cost of different TBT free antifouling and foul release systems to derive potential net benefit.

The model is also able to compare the exhaust emissions (CO₂, SOₓ) associated with the additional fuel consumption for a particular vessel.
Hull roughness penalty calculator:
The economic importance of hull condition

How Surface Roughness is Measured

Hull roughness on ships is measured as the maximum peak to lowest trough height ($R_{t50}$) expressed in microns, in any given length of 50mm along the underwater hull.

The standard equipment for measuring $R_{t50}$ values is the Hull Roughness Analyser (or Gauge), supplied by BMT (British Maritime Technology), Wallsend, UK. At each location the surface probe is manually run over a distance of 750-1000mm to generate ~10-15 $R_{t50}$ readings, the average of which is the mean hull roughness at that location.

At least 100 locations distributed around the underwater hull (including sides and flats) are required for statistical validity. The average of all these mean hull roughnesses gives the Average Hull Roughness (AHR). The graph below shows how the distribution of readings typically appears.

The Effect of Coating Roughness on Ship Performance

The effect of coating roughness on ship performance can be calculated using the Townsin formulae:

Fractional Added Resistance ($\Delta R/R$) for going from a smooth (AHR = $k_1$) to a rough (AHR = $k_2$) surface:

$$\Delta R/R = \Delta C_F/C_T = 0.044[(k_2/L)^{1/3} - (k_1/L)^{1/3}]/C_T$$

Where:

- $\Delta$ = Change in resistance, power, speed or propeller efficiency due to increased roughness
- $\Delta C_F$ = Frictional Resistance coefficient increase
- $C_T$ = Total Resistance coefficient = ([Total Resistance]/0.5 $\rho$ $S$ $V^2$)
  or very approx. = 0.018 $L^{-1/3}$ (if $C_T$ value cannot be found otherwise, and where $L$ is in metres)
- $\rho$ = Seawater density
- $S$ = Surface wetted area of vessel
- $V$ = Speed of vessel
- $L$ = Length between perpendiculars of vessel
Fractional Power increase ($\Delta P/P$) at constant speed for going from a smooth (AHR=$k_1$) to rough (AHR=$k_2$) surface:

$$1 + \frac{\Delta P}{P} = (1 + \frac{\Delta R}{R}) \left(1 + \frac{\Delta \eta}{\eta}\right)^{-1}$$

Where:

- $P$ = Shaft Power
- $\eta$ = Open water propeller efficiency

As a handy guide, the following approximate relationships hold for a Ro-Ro ship and a Tanker, which typify Liner and Bulk Cargo ships:

For Ro-Ro ships: $(1 + \frac{\Delta \eta}{\eta})^{-1} = 0.17 (1 + \frac{\Delta R}{R}) + 0.83$

For Tankers: $(1 + \frac{\Delta \eta}{\eta})^{-1} = 0.30 (1 + \frac{\Delta R}{R}) + 0.70$

Figure 1 shows the increase in power required and hence the typical increase in fuel consumption necessary to maintain vessel speed of a fast fine ship (e.g. Container Liner) versus increasing physical hull roughness.

Fractional Speed Loss ($\Delta V/V$) at constant power, for going from a smooth (AHR=$k_1$) to rough (AHR=$k_2$) surface:

$$\frac{\Delta V}{V} = \frac{\Delta P}{P} \left(n + 1\right)^{-1}$$

Where:

- $n$ = speed index = -2.15 for Tankers and Bulk Carriers.

Figure 1: Typical increase in power/fuel required to maintain vessel speed of a fast fine ship vs increasing hull roughness.

Note: Above 225 microns (which is undesirably rough) calculations are less precise, hence the dotted lines.

How Roughness is Affected by Antifouling Type

During the period 1976 - 1986, two substantial hull roughness studies were carried out. These studies showed that over time, ships generally get rougher due to mechanical damage from anchor chains, tugs, grounding, berthing, etc. and from mechanical damage, cracking, blistering, detachment, corrosion etc. of applied surface coatings. The increase in roughness was found to differ markedly depending on which antifouling type was used. With traditional antifoulings the increase in Average Hull Roughness (AHR) over time was found to be 40 microns per year, with part of this increase resulting from the reasons mentioned earlier and part resulting from maintenance painting at each drydocking (assuming no reblasting). Fouling was removed prior to measurement of roughness.

The economic importance of hull condition

For Self Polishing Copolymer (SPC) antifoulings, the average increase was found to be significantly less, at 20 microns increase in AHR per year. This reduction is a result of the polishing and smoothing action of SPC antifoulings.

Since 1986, the traditional antifoulings have been modified with reinforcing resins and are now generally referred to as “Controlled Depletion Polymer” (CDP) antifoulings (e.g. Interspeed 340). The AHR increase of these coatings is also estimated at 40 microns/year.

The three additional (to CDP), International Paint fouling control technologies may be characterised as follows:

- **Foul Release Technology** (Intersleek 425 and Intersleek 700). These products do not use biocides to control fouling but rely on a slippery “non-stick” surface to make it difficult for fouling species to adhere. Foul release systems provide a very smooth surface and because they are relatively expensive to install, ship owners and operators are generally very careful to avoid damage with vessels coated with these systems. AHR increase therefore is assumed to be only 5 microns per year.

- **TBT Free SPC Technology** (Intersmooth SPC). Proven in service on over 1,600 vessels worldwide and proven to provide an equivalent performance level to that achieved by premium grade TBT SPC products. AHR increase is estimated at 20 microns per year, the same as TBT SPC products.

- **Hybrid TBT Free Self Polishing Technology** (Interswift 655). This technology offers a balance of CDP type and SPC type antifouling properties with performance and AHR increase assumed to be midway between the two at 30 microns per year.

The International Paint Hull Roughness Penalty Calculator estimates the increase in power required per time for the four main antifouling technologies outlined based on their average increase in physical hull roughness per year. The initial roughness is taken as 120 microns which is the approximate roughness value for a typical newbuilding. Figure 4 shows the result.

**The Risk and Effect of Fouling of TBT Free Antifoulings and Foul Release Systems**

Fouling is a biological phenomenon whose occurrence is difficult to predict and control. The type, severity and extent to which fouling occurs varies greatly depending on the type of antifouling coating plus the vessel’s trading pattern and operational profile (i.e. vessel speed and activity). Only by studying a large number of vessels over extended time periods can statistically reliable information be obtained.

International Paint monitors the performance of all of its antifouling coatings through a system called Dataplan. Since 1977, Dataplan has recorded the details of the underwater hull condition of over 70,000 ships. When a ship enters drydock, the type, severity and extent of fouling on the underwater sides, boottop and flat bottom are recorded. From this information, Dataplan can calculate an overall “Fouling Rating” on a scale from 0 (completely clean) to 100 (completely fouled). Different weightings are assigned depending on fouling type. By having a sufficiently large sample number of vessels, the average fouling rating over time, which is a measure of the risk of fouling for different antifouling types, can then be assessed with a high degree of confidence.
If 100% green grass attaches to the vertical sides of a vessel (Dataplan Fouling Rating = 100) then the typical experience of ship operators shows that at least a 10% fuel penalty can occur. Using this equivalence, the % increase in fuel consumption over time due to fouling on different antifouling systems can be calculated based on their average Dataplan Fouling Ratings (a Dataplan Fouling Rating of 10 or less denotes satisfactory performance).

Figure 5 shows the increase in fuel consumption of two identical container vessels, one coated with a CDP antifouling and the other with an SPC antifouling. Initially, little difference between the systems was observed but after 18 months the CDP coated vessel picked up weed fouling on part of the vertical sides and there was an associated dramatic increase in fuel consumption.

Figure 5: Fuel Consumption of Identical Container Vessels

![](image)

The Combined Effects of Physical Roughness and Risk of Fouling on Ship Power/Fuel Requirement

The combined effects of increased physical roughness and the risk of fouling for the different antifouling types on the power/fuel required to maintain vessel speed is shown in Figures 6 and 7.

Notes:

1) There is usually less weed fouling on the flat bottom of a vessel because the light intensity is reduced, hence the power/fuel penalty is lower on the flat bottom than on the vertical sides.

2) Since CDP and hybrid antifoulings are not designed for more than 36 months in service on the vertical sides of a vessel the power/fuel penalty for these products rises sharply after 36 months.

Figure 6: Overall % power/fuel increase for a typical fast fine ship (e.g. Container Liner) vs time for different antifouling types - vertical sides.

Figure 7: Overall % power/fuel increase for a typical fast fine ship (e.g. Container Liner) vs time for different antifouling types - flat bottom.

Vessel Fuel Consumption

The “baseline” annual fuel consumption for a particular vessel can be calculated from the daily fuel usage (tonnes/day) multiplied by the number of days spent at sea per year. Multiplying this figure by (1 + the average annual % extra) fuel usage shown in Figure 6 (vertical sides) and Figure 7 (flat bottom), and then cumulatively totalling these for the specified in service period, gives the total fuel consumption (tonnes) for each antifouling type. The total cumulative fuel cost is then obtained by multiplying this by the price per tonne of the fuel.
The Hull Roughness Penalty Calculator predicts the inevitable increase in underwater hull roughness during the specified service period and combines this with the risk of fouling associated with different antifouling types. The model compares fuel usage and cost to the installation cost of different TBT free antifouling and foul release systems to derive potential nett benefit.

The introductory screens to the Hull Roughness Penalty Calculator are shown:

Welcome to the International Paint Hull Roughness Penalty Calculator (HRPC)

The Hull Roughness Penalty Calculator is a computer based software programme that predicts the inevitable increase in underwater hull roughness during the specified service period and combines this with the risk of fouling associated with different antifouling types. The model compares fuel usage and cost to the installation cost of different TBT free antifouling and foul release systems to derive potential nett benefit.

The model is based on a series of published data and assumptions including:

- Vessel fuel consumption and the effect of hull roughness
- How and why average hull roughness increases in service
- 10 year Hull Surface Condition Study (Townsin)
- Dataplan*: Mechanical Damage of vessels in service and Antifouling Performance Rating
- Fuel penalty vs. hull roughness calculation (Townsin)
- Relationship of bunker consumption to CO₂ and SOₓ emissions

Note:

Model tested and verified by external consultants.

No price changes for fuel and coatings have been factored into the in service period of the vessel.

Model assumes 380cSt grade fuel with 3.0% sulphur content.

Model used for illustrative purposes only showing theoretical benefits. Actual benefits may be different.

*The International Paint “Dataplan” performance monitoring system records the application and performance of coatings systems on over 70,000 vessels. At each drydocking, vessel details, including drydocking interval and coating performance, are recorded. Antifouling coatings are assessed for the presence of fouling (type, severity and extent) and from this unique database an antifouling performance rating can be calculated.
1. Enter Vessel Data

Vessel Data
Owner: NUFC Ship Management Co
Vessel name: Al Shera
Vessel type: Container - 110k Post Panamax

2. Bunker Information

Bunker information
Cost of bunkers (USD/te): 160 USD
2004 Av. USD/Te 165.00
Theoretical bunkers/day: 273 Te.
Actual bunkers/day: Te.
Days at sea: 320 Days
Activity%: 0.88
Bunkers per year: 87,360 Te.

Fuel per year: 13,977,600 USD
Fuel per 60 months: 69,888,000 USD

3. Select Generic Type

Recommended Scheme
Sides: Foul-Release - Intersleek 700
% Sides: 50%
Flats: Pure SPC - Intersmooth SPC
% Flats: 50%

Base Scheme
Sides: Pure SPC - Intersmooth SPC
Flats: Flats Hybrid - Interswift 655

Months in service: 60

CO₂/SOₓ Calculator
Fuel Type: 3.0% Sulphur

4. Review Result

Result
Scheme Sides/Flats Extra Fuel Over 60 months Extra CO₂ Over 60 months Extra COₓ Over 60 months
Sleek/Pure SPC 947,713 USD 18,954 Te. 355 Te.
Pure SPC/ Hybrid 2,059,671 USD 41,193 Te. 772 Te.
Potential fuel difference 1,111,958 USD 22,239 Te. 417 Te.

Potential nett benefit for 60 months 931,893 USD

The information contained in this summary is illustrative only and is based on a number of assumptions outlined to you during the presentation.
Your International Paint contact will be happy to provide you with a list of those assumptions.

References:
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