Technical paper

Fouling release coatings: why the use of friction coefficient is the optimal way to measure the hull surface impact on drag reduction.

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The importance of fouling protection

The primary role of fouling protection is to limit the increase of frictional drag as a result of surface deterioration and biofouling accumulation. Failure in this pursuit results in either increased power to maintain a given speed or reduced speed at a given input power, both of which have associated economic penalties (1). The effect of fouling on frictional drag has been quantified over the years and, depending on the speed of the vessel, and type and density of the biofouling, it can reach an increase in drag of up to 86%. The highest increase in drag is observed on vessels operating at lower speeds.

The accumulation of marine organisms on the hull adds to the total weight of the vessel and generates hull roughness, which is directly responsible for the increase in frictional drag. In that sense, hull roughness is an important factor in predicting fuel consumption and fuel savings, especially for slow-steaming vessels. Predicting fuel consumption is less reliable for vessels with a clean, fouling-free hull and higher average speed.

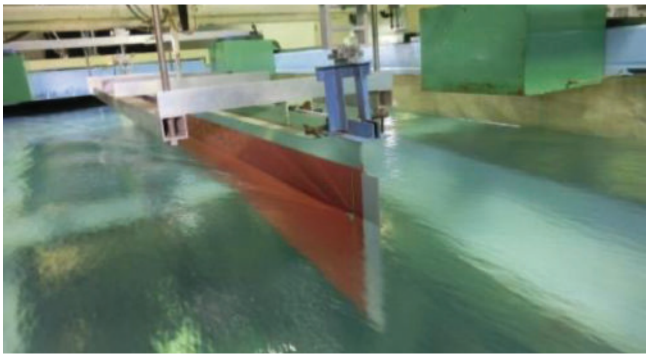
Hull roughness

Surfaces have many different scales. The long wavelength shapes are assigned to waviness and the short wavelength features to roughness. The use of a single roughness parameter gives an incomplete representation of the concept of roughness, as two surfaces may have the same value of a height parameter and quite different waviness or texture (2).

The commonly used parameter, however, when measuring a ship's hull profile is Rt(50), which is peak to valley height over a 50mm sample. Rt(50) has been generally accepted for the quality control purposes; however, it is inadequate to describe the complexity of coated hulls, especially when a correlation is required with their added drag (3). It is simply not detailed enough to correlate surface roughness with its effect on viscous drag, as it gives an incomplete, one-dimensional representation of the surface without a texture (4). The procedure adopted by the International Towing Tank Conference to correlate roughness with the added resistance of ships only accounts for a single roughness parameter being an average of Rt(50) (5).

Silicone-based fouling release coating applied on a tanker

Studies have, however, demonstrated that fouling release coatings, even poorly applied with a higher Rt(50) value of 62 µm, compared with self-polishing coatings with Rt(50) of 39 µm, had 1.4% lower drag resistance than self-polishing coatings (6). There have been other re-evaluations of the correlation between roughness and drag for fouling release coatings that demonstrated no correlation when they are characterized solely by a height parameter (7).

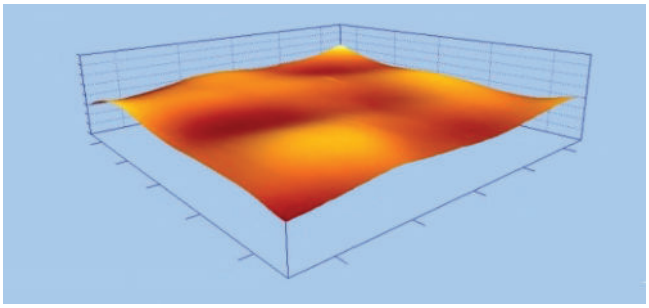


Towing tank test

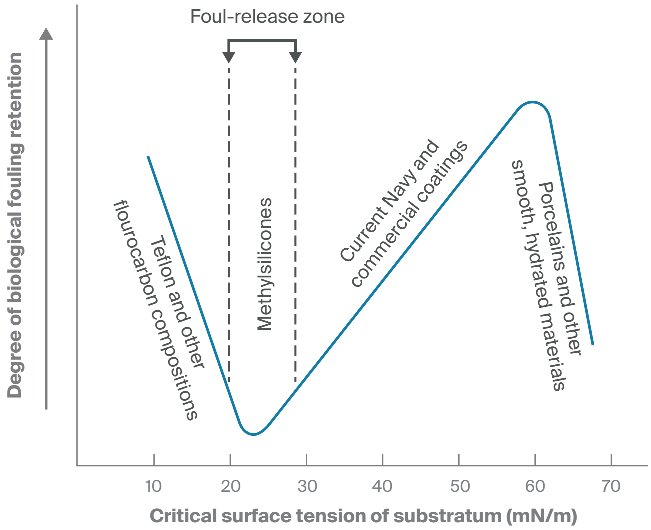
The lower drag, in the case of fouling release coatings, is associated with longer wavelengths when compared with spiky roughness of self-polishing coatings. It is, however, only one of the differences between the two technologies. The texture and surface character of fouling release coatings is fundamentally different from the surface of self-polishing coatings.

Fouling release

Silicone elastomers used in fouling release coatings generate unique surface properties of the film, such as low surface energy and low E-modulus. The non-stick and release effect typical for silicone-based coatings can only be achieved in the presence and combination of both surface properties. Additionally, silicone oils used in fouling release coatings next to their lubricant effect contribute to their surface character. The long-term effect of silicone oils on the hydrophobicity and surface tension is proved also on the coatings after immersion (8).



Graph 1: 3D surface profile scan of silicone based fouling release



Graph 2: Surface behavior of biomaterials: The theta surface for biocompatibility" R.E. Baier, 2006, supports that silicone is the optimal combination of low surface energy and elasticity.

The correlation between surface tension and fouling relative adhesion is defined by the Baier curve, which shows that the curve reaches its minimum at 22–24mN/m and that the lowest surface energy does not guarantee the lowest relative adhesion. Materials with low surface energy like PTFE (16 mN/m) do not show good fouling performance. It is only the combination of specific surface energy and elastic modulus that will provide the release effect of the film. The lower the value of elastic modulus the better the release effect.

The rheology of the silicone-based paint and its ability to level out after application also enables it to create a smooth surface with long wave lengths.

Friction coefficient

The condition of the hull will significantly influence the frictional resistance of a ship as it is a function of the hull's wetted area, surface roughness and water viscosity. Therefore, the impact of the fouling on the frictional resistance is obvious (1). However, as friction resistance happens in the turbulent flow of the boundary layer where water molecules are carried along with the ship, the surface that is in contact with that layer will affect the friction as well.

Surface free energy is a fundamental property of the surface and independent upon roughness (9). The size of the surface energy represents the capability of the surface to interact spontaneously with other materials (10) and can be easily quantified by measuring the angle that a liquid droplet makes when in contact with the coated surface.

Surface energy and wettability tested together with roughness parameters showed a large contribution to frictional resistance. Studies showed that the drag characteristics of a surface are affected by its free energy and roughness parameters. Low surface energy of fouling release is achieved by an extremely flexible PDMS polymer backbone that allows the polymer to readily adopt the lowest surface energy configuration. Consequently, this can reduce the friction of the coated surface (11).

Other studies on correlation between the hydrophobicity, roughness and friction coefficient of different coatings showed no clear pattern. For some coatings there is a linear relationship between roughness and drag, whereas others violate this relationship (12).

The most complete method to determine frictional resistance of a coated surface is a calculation of friction coefficient. This way, all relevant surface characteristics are included in the measurement:, hull roughness but also surface texture and morphology and, most importantly, physical and chemical properties of the surface, such as surface energy, wettability and flexibility.

The low surface free energy of silicone-based coating

There are several experimental techniques to measure friction resistance that include, among others, flow measurements on a flat plate in a water channel or tube, or torque measurements on rotating discs (13). The friction coefficient can be then defined in line with ITCC (14). The outcome of these measurements can be further used for CFD calculations to estimate the hydrodynamic resistance of a ship's hull coated with specific fouling control products (15).

Summary

Fouling release coatings are one of the fouling control solutions that contribute to frictional drag reduction through their unique surface, which is characterized by its smoothness and waviness combined with low surface energy and high elastic modulus. The complexity of the silicone-based surface is not well represented by surface roughness measurements only; as a result, this is not sufficient to prove its efficacy in drag reduction.

Friction measurements are a more comprehensive method that include all the above-mentioned aspects of silicone-based coatings' functionality.

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