ABSTRACT BOOK
JOINT WORKSHOP BYEFOULING-SEAFRONT

''Bridging the gap between science and industry''

Toulon, Friday June 24, 2016

Abstracts of presentations and posters from presenters:

Andrew Guerin
Dan Isaksson
Cecilia Zambrano

Marie Dale
Sander Kommeren
Kevin Reynolds (2x)
Anna Abramova
Ahmad Alsaab
Serkan Turkmen (2x)
Uma Vadamadurai Rathinavelu

Short summary (published in Seafront newsletter of June 2016) of workshop ‘’Bridging the gap between science and industry’’, in Toulon, France.

On the sunny afternoon of Friday June 24 at the end of the successful ICMCF conference, the joint workshop on antifouling was organized by the EU projects Seafront and Byefouling in the Neptune Congress Centre. Over 100 participants joint this workshop, 50/50 participants from the industry/academia.
Professor Yehuda Benayahu (Tel Aviv University) chaired the session and introduced the keynote speaker Tony Clare (University of Newcastle).
Andrew Guerin (University of Newcastle) went deeper into the academic point of view. Ana Otero Casal (University of Santiago de Compostela) added that she notices two valleys of death to bridge the gap between academy and industry in the anti-fouling research.
The industrial dimensions and linkage to academia were presented by Dan Isaksson (I-Tech Marine Paints) and Kim Andreassen (JOTUN AS) on behalf of Seafront respectively Byefouling.

The end-user was represented by Peter van Aken (Lonza) on behalf of Byefouling. Cecilia Zambrano (Minesto) showed the kite Minesto developed for marine energy converting. A Lively round table discussion with all lecturers followed, chaired by Kevin Reynolds (AkzoNobel) and Jurgen Riegler (Lonza).

As teaser for the poster session, pitches were organized on the podium to introduce the scientific challenges and solutions the posters showed. Severine Larroze, involved in the Byefouling project, won the first poster award.

Picking the winners: choosing the most promising candidate coatings from a diverse selection

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One of the goals of the SEAFRONT project is to develop a small number of coatings with antifouling performance that equals or exceeds that of existing technologies. Antifouling performance of candidate coatings is therefore tested, in the laboratory and in the field, using standard assays, which can also be applied to existing commercial antifouling coatings. The main interest of individual coating producers may be to understand the relative performance of a range of coatings that they provide for testing, in order to help them fine-tune their coating formulations. In addition, large projects like SEAFRONT need to compare the performance of many different prototypes, tested weeks or months apart, so that the best technologies can be selected for further development and testing.

Testing using consistent assay methodologies is an important part of this process, as long as all coatings are amenable to the standard assays. The inherent variability resulting from the use of live organisms for testing also means that results cannot always be simply compared between assays conducted weeks apart. Inclusion of consistent reference surfaces can help. Further complications for decision-making arise when multiple assays (using different biofouling species) give opposing results.

This presentation will briefly explore these issues and discuss methods for selecting the best among varied coatings.

Almost there! Or are we?

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Abstract:

The experiences of going from academia to industry with Selektope will be briefly presented. A lot of the learnings during this process has been related to the somewhat naive approach that we had in the beginning of the development process. Understanding or at least be aware of the challenges in the industrial development is a key to reasonable expectations. This and how some of the pitfalls may be avoided by being part of larger research program such as Seafront will be discussed. The benefits of cooperating with the various partners within the program in order to try and understand the bigger picture such as challenges and time lines in various parts of the product development process will also be discussed. The presentation will sum up part of what I-Tech has contributed with and what we have learned from the Seafront program so far.

The Antifouling Challenges for Marine Energy Developers

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Economic growth, higher electricity prices, climate change and security of energy supply stress the global need for renewable energy. The oceans form one of the least explored, and at the same time, largest renewable energy source on earth. While most tidal stream developers focus on horizontal axis turbines, Minesto is developing a tidal energy power plant, called Deep Green, which converts the low-velocity ocean and tidal currents' kinetic energy to electricity. Deep Green consists of a kite, flying under water in figures of eight. Although this novel method of harnessing tidal energy is different in many ways from conventional turbine designs, Minesto, like most conventional turbine developers, has chosen composite materials for the device structure. For all tidal energy developers corrosion is a permanent threat that can be mitigated by using an effective composite coating. Skin friction affects the lift to drag ratio and thus efficiency of the device, therefore coatings must provide low skin friction and minimize fouling. While similar conditions apply for ship coatings, the operating conditions and consequences of coating failure are unique for tidal energy converters. The SEAFRONT project enable marine energy converter developers and coatings providers to understand the relevant processes to develop fouling control solutions.

Fig. 1: Minesto's Deep Green ¼ scale device.

Biology at AkzoNobel: Bioassays, biofilm analysis and benchmarking of commercial coatings

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Bioassays are an important screening tool to provide a quick, easy and reliable method to test coating performance in a way which can differentiate between high and low performance and can be predictive of in-field performance. A range of in-house assays, developed or adapted by AkzoNobel are available, which assess experimental coatings (Fouling Release and Biocidal Systems) in a pragmatic way; utilizing multispecies, wild type population tests to simulate the dynamic range of marine species and fouling challenges a coating is expected to perform against in-field.

At the forefront of the marine fouling challenge is biofilms. Biofilms constitute the most ubiquitous and complex fouling challenge; subject to constant dynamic changes and heavily influenced by external factors, including the nature and properties of the coating they reside on.

Typically, fouling control performance is assessed using fouling abundance which, in most instances, is a suitable indicator despite being somewhat subjective. This assessment method however provides limited information when analyzing biofilms.

Using the capabilities of our SEAFRONT partners alongside in-house capabilities new methods to quantify, sample and analyze biofilms have been developed; providing insight to the physical, biological and chemical characteristics of biofilms and the influence of the coating and other environmental conditions on these characteristics.

Fouling control performance and coating-fouling interactions are being benchmarked using a range of commercial coatings in bioassays, field immersion trials and vessel test patches. Not only does this provide data on the in-field performance of these coatings, but as part of the SEAFRONT project the data also provides tiered, state of the art performance standards to which experimental formulations can be compared and the level of improvement quantified.

Patterned photo-crosslinking of thermo-responsive hydrogels for dynamic surface structures.

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The development of smart surfaces that have dynamic properties have been actively pursued in recent years.[1] For example thermoresponsive hydrogel surfaces have been used for the investigation of cell behavior and even as potential antifouling coatings.[2-4] The dynamic properties of such coatings are thought to actively help prevent and/or detach micro- and macro-fouling organisms. Here, we report a novel approach for creating thermoresponsive hydrogel coatings with a switchable surface topography on a single substrate. The hydrogel coatings are based on the thermal responsive poly(N-isopropylacrylamide) (PNIPAm) utilizing a solubility change at the lower critical solution temperature (LCST) at around 32 °C. The addition of a photo-crosslinking monomer to the PNIPAm polymer provides the ability to cross-link the polymer after polymerization. The use of a polymer makes it possible to make coatings on a single substrate by, for example, spray-coating. The polymer coating is cross-linked by multiple UV mask illumination steps resulting in a cross-link density pattern in the coating. This results in a predesigned surface topography when swollen. Due to the thermoresponsive properties of the polymer, the hydrogel can be switched to a smooth state when the temperature is increased and back to a structured state with a decrease in temperature. A smart dynamic coating that changes its surface properties with temperature has been created with potential as an active antifouling coating.

[1] Mendes, P.M., *Chem Soc Rev,* **2008**, 37, 11, 2361-2580
[2] Ista, L.K., López, G.P., *Journal of Indust. Microbiol. & Biotechnol.*, **1998**, 20, 121-125
[3] Molina, M.A., Rivarola, C.R., Broglia, M.F., Acevedo, D.F., Barbero, C.A., *Soft Matter.* **2012**, 8, 307.
[4] Yu, Q., Ista, L.K., López, P., *Nanoscale*, **2014**, 6, 4750

Connecting cutting edge research with end-users on the leading edge

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There is no shortage of cutting edge research looking into the identification, exploration and development of novel fouling control technologies, methods to explore fouling behavior and mechanics or in methods to explore the fouling control performance of these new technologies. Despite the volume of endeavor and the frequency of early promising results, very few technologies evolve beyond laboratory bioassays or small scale field trials. A significant reason for this shortcoming is a knowledge and communication disconnect between academic research and industrial end-users. This disconnect is a consequence of limited contact between researchers and end-users and the absence of a pathway from laboratory to in-service trials without the route provided the involvement of an established coatings company.

Within the SEAFRONT EU funded project a substantial effort has been made to firstly build a network of strong relationships between both academic and industrial researchers and the end-users that will ultimately exploit the technologies they develop. In addition to this, the importance of developing new technologies for the emerging markets of deepwater oil and gas extraction, marine renewable power generation and aquaculture is embedded in all technology streams. Understanding that requirements in these environments differ from the traditional ones associated with marine shipping is being used to enable customised fouling control solutions tailored to the in-service and operational variables of a particular end-user market.

SEAFRONT aims to raise multilateral awareness of each party's successes, activities and needs. The multidisciplinary nature of the consortium end-user group and the access provided to their infrastructure is a superb opportunity to gain in-service performance data of prototype technologies. Furthermore through the sampling protocols being employed, a wealth of information relating to the environmental conditions and fouling characteristics and how this varies from location to location, end-user to end-user and between laboratory and field can be obtained.

The future of fouling release: Performance, Practicality & New opportunities

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The current state of the art fouling control coatings such as Intersleek® 1100SR are the result of decades of research, development, testing and optimisation. As a result, the magnitude of their fouling release performance is close to optimum with them displaying high removal of microbial, weed and animal fouling at low hydrodynamic shear. This results in significantly improved fuel efficiency and reduced CO_2 emissions for shipping vessels.

Despite the reduced drag and fuel consumption, enhanced environmental profile (biocide free and high volume solids), superior aesthetics (ultra-smooth surface and excellent colour retention) and operational flexibility that Intersleek® 1100SR delivers to a customer (in comparison to a typical self-polishing antifouling product) the vast majority of the world shipping fleet continue to use biocidal based products. In other industries and end-uses such as oil & gas exploration and extraction, underwater surveying and marine renewable energy generation, at present in the majority of cases no fouling control technology is employed. The factors that contribute to these situations are based upon historic precedent, product perceptions, practical considerations and cost. The marine shipping market is conservative and risk averse and as a consequence is generally slow to abandon established practices and adopt new technologies. Fouling release coatings are rightly perceived as highly advanced technologies although they are also sometimes incorrectly viewed as being unsuitable for certain vessel types and operational profiles based upon isolated experience with earlier iterations of the technology. Whilst this is the case, some practical considerations including the complexity of the scheme and impact on yard throughput at new building and maintenance and repair still remain to be addressed.

The purpose of this presentation is three fold:

- To review the attributes of the current state of the art in fouling release technologies and examine the perceived barriers to widespread adoption.
- To highlight the opportunities for fouling release technologies outside of the marine shipping market.
- To showcase new fouling control concepts which may address existing concerns, deliver further enhancement of fouling control performance and initiate the expansion of the use of fouling release technologies in marine shipping and in new market sectors.

Study of gene expression along the settlement process of barnacle *Balanus improvisus*

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The barnacle *Balanus improvisus* is a common species in biofouling communities along temperate waters. The barnacle cyprid larva displays a complex exploratory behaviour prior to selection of a suitable settlement site. Cyprids of *B. improvisus* demonstrate clear preferences for some types of surfaces and actively reject surfaces with particular properties. However, there is a lack of knowledge on molecular mechanisms underlying the settlement behaviour. We performed deep RNA-sequencing to compare transcriptome profiles from four different stages along the settlement process, namely i) free swimming, ii) close exploration, iii) attached cyprids and iv) early juveniles. Methods were optimized so that sufficient and high-quality RNA was obtained from only 20 cyprids. Preliminary analysis revealed interesting changes in gene expression pattern along the settlement progression. The transcriptome profiles of the free swimming cyprids and cyprids during close exploration were similar. However, there are certain genes specifically upregulated in the close exploration stage. The transcriptome of attached cyprid was considerably distinct from the other stages in terms of a large number of upregulated genes. Majority of these genes are involved in molting and tissue remodelling during metamorphosis. In summary, for the first time a trascriptomic approach has been used to analyse gene expression during the surface exploration phase of settlement process in barnacles. Our study provides new insights into mechanisms of barnacle settlement and creates a basis for designing new targets for antifouling research.

Automatic Classification of the Settlement Behaviour of Barnacle Cyprids

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Barnacles are among the most widespread and troublesome of marine biofouling organisms. Their ability to colonise a wide variety of surfaces, fast growth to a relatively large size, and shell growth characteristics contribute to their traditional prominence as targets for fouling control. The current emphasis on research and development of non-polluting coatings that prevent fouling through non-toxic means is focussing attention on deterrence and/or interference with adhesion during settlement. Despite decades of research on barnacle larval settlement, there is still much to learn that new techniques or technologies applied from other disciplines could facilitate. The pre-settlement behaviour of the cypris larva can be classified under four broad categories: swimming; wide search; close search; and inspection Cyprids spend most of the time swimming and therefore tracking only one cyprid for a short time is not an efficient method. Alternatively, tracking multiple cyprids poses the difficult challenge of separating touching or overlapping cyprids. Further, treatment of cyprids as signal points (as is the case for most commercial software) and estimating behaviour based only on speed and trajectory inevitably produces an unacceptable degree of error. Here, we outline the development of a new tracking system and novel classification system for identifying and quantifying the exploratory behaviour of cyprids. The tracking system is specifically designed to follow cyprids and record their motion. Using only a single camera the system can reliably track multiple cyprids simultaneously for long periods. The tracking system thus enables the user to conduct long-term experiments (hours) with minimal intervention and opens the door to the in-depth study of pre-settlement behaviour. In the classification system, each cyprid is represented by three key points, and then the relationships between movements of these points are analyzed to automatically and reliably partition exploratory behaviour into wide search, close search and inspection events; thus enabling more advanced and informative studies of the pre-settlement interaction of barnacle larvae with developmental antifouling coatings.

Design of pressure drop section to measure frictional drag of fouling control surfaces

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The development of test methodologies for the evaluation of the hydrodynamic performance of fouling control surface including the effect of coatings and biofilms is particularly complex as the turbulent flow regime experienced on the surface of a ship needs to be simulated in experimental facilities. Using coated flat test panels in narrow flow channels (i.e. flow cells) is less complex, more robust and attractive to investigate the skin friction characteristics of these panels in fully developed turbulent flows.

Within the framework of the EU-FP7 project SEAFRONT [1], Newcastle University's School of Marine Science and Technology (UNEW-MST) enhanced their existing flow cell measuring section, which is used for classical biofouling adhesion strength tests, with a sophisticated pressure drop measurement section to evaluate the skin friction characteristics of flat test panels.

This new section provides effective measurements of the skin friction characteristics of standard UNEW test panels (218mmx600mm) in clean and biofilmed conditions in seawater. The new section also allows to fit an enhanced adaptor, which can accommodate number of micro slides, to conduct classical biofilm adhesion strength tests as well as the pressure drop measurements for skin friction analysis.

In this study the design and numerical optimization of the new pressure drop section as well as its calibration process are presented. The physics of the flow were simulated by solving the Reynolds Averaged Navier Stokes (RANS) equations. An LDA window was introduced in the test section to calibrate the system by measuring the flow profile.

The experiments convincingly show that the new pressure drop section can simulate typical boundary layer flow regime around a commercial ship and can be thus successfully used to measure the drag performance of clean and biofilmed (mainly slime) coatings in seawater or fresh water. The measured data shows a good agreement between the numerical predictions.

[1] Seafront "Synergistic Fouling Control Technologies ", 2013, Annex-I Description of Work, EU-FP7 Collaborative project, Grant agreement no: 614034

Dynamic biofilm growth and collection using a strut arrangement on a catamaran vessel

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The hydrodynamic drag of coating differs depending on the condition of the coated surface whether it is clean or biofilmed. The effect of biofilm on drag performance of coatings applied on test panels can be evaluated using laboratory based testing facilities (e.g. purpose built flow cells etc.). Collecting biofilm, preferably on flat test panels attached to ship hulls, therefore will enable to conduct drag tests to evaluate the effect of biofilm as well as that of clean coating on the skin friction drag. However, attaching test panels on a ship hull is challenging due to the attachment procedure and techniques (e.g. using magnets, screwing and welding) as well as removing difficulties and inconveniences (e.g. need for dry-docking, using divers, waiting periods etc).

In order to explore the effect of biofilm on coating performance and easing some of the above stated challenges of collecting dynamic biofilm samples, Newcastle University has been contributing in the EU-FP7 project SEAFRONT[1] and hence recently designed and manufactured a flexible strut arrangement. This arrangement is deployed underneath the moon pool plug of the University's research catamaran, The Princess Royal, as shown in Figure 1(left). The twin struts of the arrangement can accommodate (2x4 =) 8 off, so-called "UNEW standard test panels" as also shown in Figure 1(right).

This study presents a review of the design, manufacture and operation of the strut arrangement in collecting dynamic biofilm in North East coast of England. The experience shows that the strut arrangement effectively facilitates growing and collection of biofilms on the standard test panels under authentic conditions in a short period of time.

Fig. 1: The twin strut system with dynamically grown biofilms on coated surfaces deployed underneath (on the left) and deployedon board (on the right) of the RV Catamaran Princess Royal for inspection.

[1] Seafront "Synergistic Fouling Control Technologies ", 2013, Annex-I Description of Work, EU-FP7 Collaborative project, Grant agreement no: 614034

Electrochemical study of epoxy coated mild steel in different aqueous environment

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The present study investigates microbiologically influenced corrosion (MIC) of marine coating systems on mild steel in three different aqueous environments: natural seawater, artificial seawater and 3.5 % sodium chloride (NaCl) electrolyte. Three types of epoxy-based coatings, in both intact and scribed condition, were investigated using electrochemical and microscopic techniques. Electrochemical impedance spectroscopy (EIS) was used to study the evolution of the capacitive and resistive behaviour of the intact and scribed coating systems with immersion time in various aqueous environments. Furthermore, the delamination behaviour of the scribed-coating systems after exposure was studied by measuring the surface potential of the coating/metal interface using Scanning Kelvin Probe (SKP). It was found that the reduction of impedance of the coatings that were exposed to natural seawater was significantly higher with time compared to that of those exposed to the artificial seawater and NaCl electrolytes. This is attributed to the formation of a marine biofilm on the surface of the coatings and possible increase in ingress of moisture due to the biofilm-coating interaction upon immersion in natural seawater. The biofilm population and morphology on the different coating surfaces were further analysed using scanning electron microscopy (SEM) and epifluorescence microscopy. Conventional corrosion research of marine coatings is performed by immersion in electrolytes that simulate the natural environment such as artificial seawater (containing only the soluble salts that are found in seawater) or NaCl solution. This study demonstrates that chloride-containing or artificial seawater environment does not fully represent the marine ecosystem exposure where microorganism are present, influencing the corrosion protective properties of the coating.