Publishable summary

Marine biofouling is a term used to define the adhesion and colonization on seawater submerged surfaces by a diversity of marine organisms (**Figure 1**). It can cause serious detrimental effects on such surfaces and subsequent economic and environmental penalties, particularly for marine transportation. It is responsible for hydrodynamic drag increasing in ships and thereby fuel consumption and greenhouse gas emissions. For instance, biofouling has been estimated to raise drag by much as 40% and fuel consumption by as much as 30%, being estimated to lead to powering penalty as high as 86% (IMO 2003). An efficient antifouling coating is estimate to provide annual fuel savings of $60 billion and reduce annual gas emissions by 384 million tons of carbon dioxide and 3.6 million tons of sulphur (IMO, 2009). Protection surface strategies against such bio-attach have been widely pursued by the marine industry. Antifouling biocide-releasing coatings is recognised to be the most effective, but despite its effective antifouling action, this strategy evidenced serious drawbacks, such as the requirement of an effective mass transfer between the bulk flow and the biofilm to ensure the effectiveness of the chemical. But the critical drawback is mainly associated to the continued releasing of biocides into the environmental, which associated to their ecotoxicity have been leading to harmful side effects on ecosystems. As a result, the use of such antifouling agents have been regulated internationally or even banned (e.g. TBT). Recent regulations (Regulation nº528/2012) have been highly limiting the availability of efficient antifouling biocides. Greener antifouling alternatives are sought in order to answering to this economic and environmental challenge in marine shipping business. Several non-biocidal technologies have been emerging, but are still evidencing technical or environmental limitations (*Elisabete R. Silva, Olga Ferreira, João C.M. Bordado, Ho-Chun Fang, Stuart Downie, Stefan M. Olsen.* Marine coatings: A Systematic Study on structure-property relationship of potential covalently immobilized biocides. Transport Research Arena 2014. Published on-line, May 2014: http://www.traconference.eu/papers/pdfs/TRA2014_Fpaper_18102.pdf. Therefore, innovative approaches for combatting Biofouling are sought, which would be an important contribution toward marine transportation.

Figure 1. Biofouling on Ships´ Hulls, which lead to organisms deposition and biocorrosion effects

The **Mission of FOUL-X-SPEL Project** is to develop a novel approach for the biocides fixation in polymeric paint matrices, aiming to overcome the above limitations, mainly regarding environmental harmful effects promoted by the releasing of toxic biocidal agents, as well as the retrofitting associated issues. The ultimate goal of this project, supported by the European FP7 Programme - THEME [SST.2011.1.1-1.][Green retrofitting through optimization of hull-propulsion interaction], is to provide an innovative non-release coating for ships' hull protection.

This new approach is aimed to be achieved by research and innovative work provided by the collaboration of 10 international partners, which ultimate goal is to offer an antifouling coating that avoids the leaching of toxic substances to the seawater, together with a long-term effect of surface protection (up to 90 months of exposure into seawater). The new surface coating technology will minimize the surface roughness and improve hydrodynamic properties of hulls, consequently minimize the effect of Green House Gas (GHG) emissions. The main expected results and also indicators of the project work plan progress can be summarised as:

- To select and carefully analyse the feasible to immobilise bioactive molecules in a polymeric matrix, in compliance with regulatory requirements and particularly under the European Biocidal Products Directive (BPD) for environmental concerns;
- To provide a coating with a low initial friction with water, maintaining the hulls' surface free of fouling;
- To provide prototypes and also the coating applied to surface of ships for sea exposure, using the developed paint and conventional antifouling coatings (for comparative studies);
- To reduce the immobilisation period, in dry docks, for hulls maintenance;
- Develop modular and cost-effective retrofitting technologies and environmental friendly processes for yards;
- Develop accurate assessment tools (mathematical models) for the determination of the environmental, energy and operational benefits, including energy saving of retrofitting solutions (hull-propulsion interaction) taking into account the remaining life cycle;
- Develop solutions and best-practice guidelines for efficient, safe and environmentally friendly retrofit processes, especially in which concerns surface protection.

If achieved these expected results will evidenced a great gain in ship's resistance, since the painted surface will remain smooth and durable for a longer period of time. This, in turn, implies lower fouling on the hull and lower friction resistance. As a result, the fuel consumption will lessen, leading to greater energy savings. All the above will open the way to "green-shipping", which means less environmental impact during voyages on sea (lower biocide impact on marine ecology) and air (lower SO_X, NOx and CO_2 emissions). Other expected impacts are:

- ✓ Improvement of energy management by cleanness conditions of hull surface;
- ✓ Reduction of immobilization in shipyards for treatment of hull and hull repainting with conventional antifouling paints;
- ✓ Reduction on cost of hull maintenance works;
- ✓ Better shipping management concerning the availability of ship for commercial operations;
- ✓ Accomplishment of mandatory requirement of International Convention on the Control of Harmful Anti-fouling Systems on Ships;
- ✓ Save money on fuel consumption up to 30%;
- ✓ Cleaner and environmental friendly cruise ships.

To achieve such goals the FOUL-X-SPEL project is organised by twelve main work packages with several inter-linked activities. A detailed description of the main tasks and objectives in each work package can be found in the project website: **http://www.foulxspel-antifouling.com/**. Briefly, Managements activities of the project are planned and descripted in WP1. R&D tasks (WP2 to WP4) are planned to identify and select bioactive molecules, able to be immobilised in the coating matrix. Paint interactive formulation and assessment in terms of biocide immobilisation, activity, paint biodegradability, ecotoxicity and mechanical properties will be also included in WP4. From WP5 to WP10 lab and field tests (ships and developed prototypes) activities at different scenarios, to validate and certify the new antifouling coating are included. Comparative studies with reference paints will be also performed, which will constitute inputs for a benchmarking assessment, techno-economic validation and technical guidelines for Industry scale application (WP11). WP12 comprises dissemination and exploitation of the project results (workshops, conference participation, publications, forum of stakeholders, etc.).

The tasks planned have been performed by the Project Consortium since the beginning of the Project (December 2011 until November 2014). So far, the main activities and achievements are the following:

- ✓ Potential biocides and bioactive compounds have been selected and functionalised to their further effective immobilisation in polymeric paint matrices. A new process for the covalent immobilisation of biocides in polymeric matrices had been successful developed and protected by a patent application: Elisabete R. Silva, Olga Ferreira, João C.M. Bordado, *Functionalisation process for the biocides immobilisation in polymeric matrixes*, Patent application PT Nº 10809, 12-12-2014.

- ✓ Ecotoxicity for Alga, Daphia Magna and V.Fisheri have been performed for the functionalised biocides and for the starting biocides. All tested biocides revealed toxic for the tested organisms, with the exception of one functionalised biocide, which was not toxic for Algae and Vibrio Fisheri.

- ✓ Biodegradability studies (OECD 301F tests) evidenced that all tested biocides, including functionalised and non-modified biocides, are not biodegradable accordingly to the followed standard test.

- ✓ Paint formulations: different strategies had been followed for the immobilisation of biocides or bioactive compounds in two different polymeric matrices, *Polyurethane and polysiloxane based matrices,* in order to increase the chances of success. The first strategy applied the previous mentioned biocide functionalization process, and a second strategy approach followed a similar biocide immobilisation approach, but using cross-linkers instead of using the functionalisation process. From those strategies, suitable polymeric formulations for both polyurethane and siloxane based matrices has been identified and optimised. As a result, two main paint formulations for ship trial tests were generated: **1.** a polyurethane paint containing immobilised Econea and Irgarol; and **2.** a silicone based paint containing immobilised Econea.

- ✓ In addition, and for comparative purposes, a polyurethane paint formulation containing immobilised Econea was also generated. Furthermore, zwitterion compounds immobilisation was also successful achieved in polysiloxane-based coatings, and accurately protected by a Patent application: S. M. Olsen, P. C. W. Thorlaksen, D. M. Yebra. *Polysiloxane-based fouling-release coatings*. Application WO 2014177159 A1, 2014.

- ✓ Prototypes for lab and field tests were design, constructed and painted, following the accurate painting procedures, with conventional antifouling paints and new paint formulations. They were exposed at different seawater at static conditions: Gulf of Elefsis (Greece), Spain-Mediterranean sea, Singapore – Indian ocean, Peniche – Atlantic sea (Portugal) and Southampton (England). The results were interesting for at least 3 months of exposure, for longer periods (8 months) there were mainly promising for the silicone based paints. Nonetheless, it should also be not forgotten that such tests, performed at static conditions, are much aggressive than at non-static conditions (shipping). On the other hand, the paint formulations evidenced, as expected, different performances at different seawater conditions and biota. Therefore, such kind of tests should be continued to support the ship field trial tests at least until complete a year of continues testing and probably adjustments on the paint formulation may be required, depending on the testing conditions (e.g. pH, temperature, salinity, biota), particularly on the biocides content.

- ✓ Paint test and assessment in what concerns fully characterisation of basic paint properties such as: adherence, hardeness, thickness, erosion, abrasion, washability, wettability, environmental compatibility, drag friction measurements, fouling accumulation and its relation with coating performance and ship hydrodynamics, durability against mechanical stresses and performance in corrosive environmental (paint release), among others, were performed on the developed prototypes. In addition, a specific prototype for drag friction measurements (M. Conte, B. Pinedo, IK4-Tekniker. *Device and method for measuring* *the drag force between a liquid and a surface*. P140368EP, Application Nº 14382060.3, 2014 Aug 7) was developed and attached on ships trial tests, in order to be exposure to similar conditions. The final goal is to ensure that the formulated paint can maintain the aforementioned characteristics for a longer period of time, assuring minimum fouling of the hull and maximum fuel and energy savings.

- ✓ A Mathematical Model to estimate/demonstrate the benefits of the new paint for the existing ships in terms of energy efficiency, environmental efficiency as well as Life cycle costs, was developed based on existent real data. This Model is of high importance for shipping industry, since it become crucial to predict and evaluate the energy efficiency and environmental efficiency on paint formulations. In addition, this model was developed in order to be suitable not only for any paint formulation but also for the different types of existing ships. This particular work received an award as *Best Industrial/Application Paper Award at TRA 2014* (Demirel, Y.K., Khorasanchi, M., Turan, O., Incecik, A. *CFD approach to resistance prediction as a function of roughness*. In: Proceedings of Transport Research Arena Conference 2014. 14 - 17 April 2014, Paris La Défense, France.).

- ✓ ENP Fishing ships (***Figure 2 and 3***) with the newly developed formulations and supported by the above achievements have been launched in 2014. Previous field trial test have been performed at similar conditions with reference commercial antifouling paints, for further performances comparisons. In addition, there was also launched a sea trial supported by SU's research yacht. These field tests will continue to be monitoring to assess the antifouling performance of these products even after FOUL-X-SPEL ending.

- ✓ Authorisations from legal entities were already been acquired for the future field trials with the new developed paint.

- ✓ The techno-economic feasibility study of the new FOUL-X-SPEL paints was also carried out and the techno-economic feasibility of the paint for different types of existing ships was demonstrated.

- ✓ Guidelines/best practices for implementation/maintenance of the coatings was developed to achieve the best performance and best industrial practices with regards to energy efficiency and environmental impact technical guidelines for industry scale applications were provided.

- ✓ Publications and communications in conferences can be found in FOUL-X-SPEL Project Website. More dissemination activities are planned (e.g. Joint Conference with LEAF Project in March 2015, at Brussels, details will be published).

Figure 2. Vessel "Mar Português" painted with a new FOUL-X-SPEL silicone based non-leaching coating. Field trial test launched in September 2014. A drag friction prototype was fixed to the vessel (right).

Figure 3. Vessel "Infante Dom Henrique" painted with a new FOUL-X-SPEL polyurethane based non-leaching coating. Field trial test launched in October 2014.

FOUL-X-SPEL Project website: http://www.foulxspel-antifouling.com/

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