Fouling control using air bubble curtains: protection for stationary vessels

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There is an increasing need by the marine industries for effective non-toxic control of fouling. One of the major limitations of new fouling release coatings is that they cannot protect structures whilst stationary and will not release certain fouling organisms when vessels are operating at low speeds. This is a major problem for slow or infrequently moving vessels and for vessels docked in tropical waters where fouling pressure is extreme. This paper describes novel technology (provisional patent # 2008905482) to protect vessels whilst stationary using air bubble curtains. The results of several panel tests and one hull patch trial demonstrate that this technique is a simple, cost-effective means to complement fouling release coatings whilst vessels are in dock

AUTHORS' BIOGRAPHIES

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John Lewis completed undergraduate and postgraduate studies in marine biology at the University of Melbourne in 1977, then joined DSTO and went on to complete a 30-year career as a scientist in that organisation. His primary research interests were on marine biofouling and its prevention, and the effects of RAN activities on the marine environment. John left DSTO in early 2008, and now works as a marine consultant.

INTRODUCTION

Biofouling is the colonisation of a submerged structure in the marine environment. It begins within minutes of immersion and has several stages including conditioning by bacteria, the development of a slime layer or biofilm and the settlement of larger calcareous organisms such as tubeworms, barnacles and encrusting bryozoans. Fouling of submerged surfaces is an enormous problem both economically and environmentally. An efficient antifouling system is essential to maintain operational performance,[1] reduce fuel consumption[2] and cleaning costs,[3] and prevent the translocation of marine pests.[4] The ban on all TBT-based antifouling coatings[5] and a growing realisation of the harmful affects of biocide antifouling systems[6–8] has lead to a search for non-toxic alternatives to control fouling.

A broad range of novel antifouling technologies have been trialled, including altering the surface roughness,[9–11] changing the wettability,[12] electricity,[13] sound waves[14] and mimicking natural defences in marine organisms.[15,16] These novel techniques have had mixed success. So far, no non-toxic strategy has achieved broad-spectrum, long lasting, antifouling effects in the field.

A new method to control fouling which has gained increasing attention in recent years is foul-release coatings (FRCs).[17–19] The principle behind FRCs is that by reducing the adhesion strength of attached organisms they will be easily removed when a vessel moves, resulting in a self-cleaning effect. However, FRCs are not suitable for all vessels, particularly slow moving vessels (< 8–10 knots) or those that are docked for long periods. Anecdotal evidence has shown that FRCs do foul, particularly in tropical waters and not all fouling organisms are removed (particularly encrusting bryozoans and tubeworms) even at high operating speeds. Therefore a technology which could complement FRCs and stop biofouling attachment whilst the vessel is stationary would have universal appeal.

Early research on air bubbles for antifouling dates back to a 1937 patent.[20] A study in 1946 examined air bubbles on glass panels and on a 29-ft vessel in short term exposure trials. The optimal size of perforations, spacing and flow rate were described for plastic tubing and copper pipes. Barnacle settlement was reduced on active bubble treatments in trials ranging from 2–25 days.[21] Another study examined the use of ozone bubbles to reduce fouling, but only minor reductions in barnacle settlement were observed.[22]

In this study the use of air bubbles was examined in long-term field exposures to reduce fouling settlement. Spargers delivering compressed air were fitted on v-shaped wings to mimic the angle of a ship's hull. Streams of air-bubbles were released onto test panels and the subsequent fouling was assessed monthly and compared to control test panels that did not have air bubbles. The air spargers were then scaled up to be active over a section of a vessel and its efficacy assessed over the peak fouling season in Victoria, Australia.

METHODS

Air bubble experimental design

Test rig description

The air bubble fouling control experiments were performed at DSTO Melbourne's test raft facility at BAES shipyards, (formerly TENIX) Melbourne, Australia (37° 51' 50"S, 144° 53' 41"E). Wings were attached to submersible frames on which six acrylic panels (300mm x 150mm x 3mm) were attached to each face (North and South) of a winged frame. Fig 1 depicts the test set-up used. The v-shaped wings were set at 22.5° to the vertical. On one of the frames a sparger delivering compressed air was attached to the bottom of each face of the frame.

A sparger was attached to the base of each test wing in such a way that the bubbles would be in close contact straight away and travel up the wings, directly scouring the test panels. The air was supplied to the spargers via a compressor housed on the pier. In early trials the flow rate was controlled by one flowmeter. However, upgrades to the air supply lines were gradually made to improve reliability and stability.

A control was always performed that was in all ways identical except for the absence of bubbles.

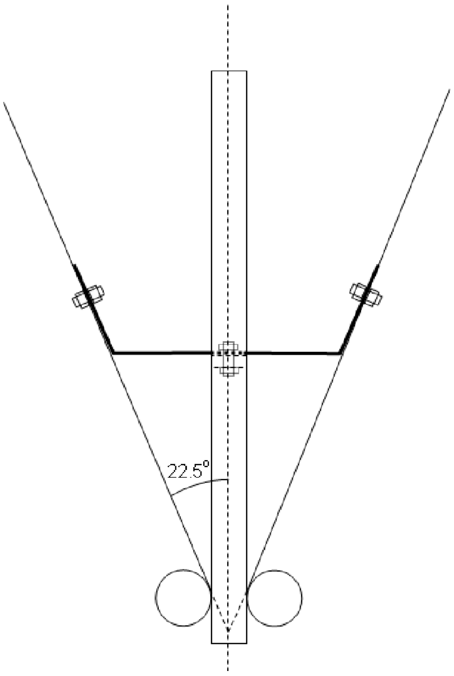

Fig 1: Schematic of the winged frames used to hold the acrylic panels and air spargers

Initial acrylic panel trial

An initial trial was performed over seven weeks during the peak fouling season (Dec 2004-Jan 2005). This trial used only sandblasted acrylic panels with no surface coating. The air was delivered using a commercially available (Pope^{TM}) water weeper hose (3–8 l/min) adapted to take air fittings. The soaker hose only covered two-thirds of the active test panels and left an additional control space on the edge for additional comparison. A duplicate control without any air bubbles was submerged at the same time.

Long term FRC trial

The next trial was designed to test the long term performance of exposure to air bubbles on International Paints Intersleek 700® coated panels. The test panels were submerged from December 2005 until May 2007. The spargers were changed for this trial to a Newair porous HPDE cylindrical diffuser from Patrick Charles Pty Ltd. At inspection the spargers were wiped to remove any settled fouling. The air flow rate to each sparger was 5 l/min. Fig 2a shows the Intersleek painted panels and sparger set-up prior to submersion.

Trials with ozone

During the 2005–2006 fouling season ozone was added to the air supply at concentrations varying between 16–180 ppm. The spargers for this trial were the soaker hose used in the demonstration trial. During the trial the ozone in the ambient air above the test panels was measured using Kitagawa® AP-20 Pump and Kitagawa ozone detection tubes (part numbers 182U, 182SA and 182SB). Acrylic panels were used with a painted patch of Intersleek grey and Intersleek black. Fig 2b shows an example of the test panels prior to submersion.

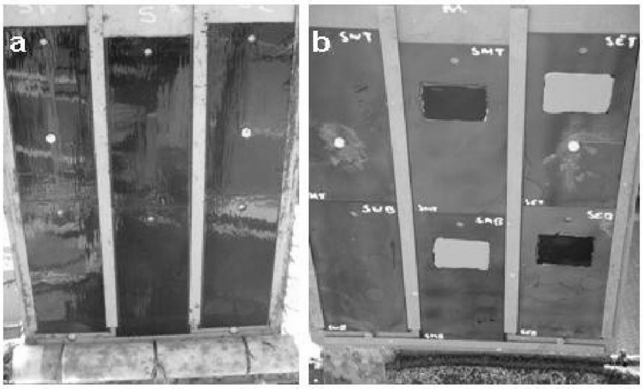

Fig 2a: Acrylic panels entirely coated with Intersleek prior to the commencement of the long-term field trial; b: Sandblasted acrylic panels with Intersleek painted patches prior to the ozone trial

Remediation trial

At the completion of the experiment the spargers were taken off the frames and placed on the controls to assess whether air bubbles could remove already established fouling organisms. This trial lasted ten weeks after which both frames were removed from the field.

Test panels

Acrylic panels were sandblasted (< 30µm grit) and coated with Intersleek 700. This coating is a silicone-based, three-pack elastomeric paint marketed as a non-toxic fouling release coating for ship hulls and other underwater surfaces. The coating of acrylic panels with Intersleek involved two systems, a tie coat and a finish coat. Each is a three pack product, consisting of a base, a hardener, and an accelerator. Each coat was applied by brush.

Fouling assessment

The percentage growth of marine fouling organisms was assessed monthly except in winter when fouling was recorded bi-monthly. Edges where the panels were not coated with FRC or where the bubbles could not reach the panels or where damage to the panels had occurred due to rough seas were not included in the assessments of fouling cover.

Prototype system testing

This trial was conducted to determine if the air bubble curtains could be practically scaled up to be effective on the hull of a vessel. The spargers were changed for this trial to Raubioxon Plus pipe aerators (REHAU, Germany) with a membrane made from silicone elastomer. Three air spargers (1m long) were deployed at HMAS Cerberus, Victoria, Australia (38° 18' 16"S, 145° 11' 1"E) approximately 3m below the water line on the 29 November 2007. The spargers were fixed to PVC piping and bolted to the wharf (Fig 3); when the vessel docked the air bubbles were effective in approximately a 1m section of the hull towards the forward starboard side of the vessel. The vessel, a twin diesel powered aluminium workboat (length oa - 12.42m, depth amidships - 2.33m, displacement - 12850kg, power - 2 x Caterpillar 3160M diesel engines at 137shp each, survey - Class 2C, speed max - 10kt) was coated with Intersleek 900 and cleaned the day before the air bubble experiment commenced.

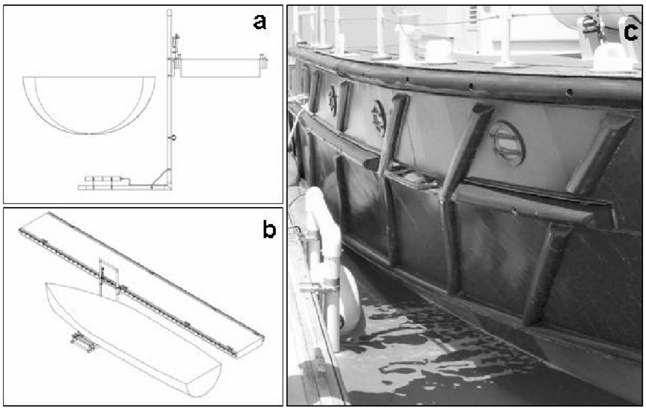

Fig 3: Experimental set up for the vessel patch trial, a) front view of the vessel patch trial set-up, b) layout view of the system on the floating wharf, and c) photograph of bubble curtain emerging from under the test vessel

The air was supplied at 8 l/min per linear metre using an Evolution Aqua® (Airtech AT-40) aerator.

Video footage of the vessel's hull was taken at regular intervals throughout the trial. The trial ended when the vessel was slipped on the 12 March 2008. A full assessment of the fouling cover was then undertaken and the vessel was cleaned with a high pressure hose. The vessel was mostly inactive over the trial period; however it was used occasionally in rough conditions at a speed of up to 10 knots.

Hull roughness measurements were taken on several sections of the hull at the completion of the trial and compared to hull roughness values for the clean vessel. A BMT Mark 111 hull roughness analyser was used.

RESULTS

Field trial 1 - sandblasted acrylic with FRC patches

The demonstration trial was abandoned prematurely due to bad weather which damaged the test panels. The last inspection of the test frames occurred seven weeks into the trial and the results are shown in Table 1.

After seven weeks there was already a noticeable difference in species diversity between the active bubble panels and the control (Table 1). Also, the abundance of the hydroids and barnacles on the bubble panels was reduced. The rubber soaker hoses were also heavily fouled with hydroids and barnacles.

Long term FRC trial

For the long term FRC trial the air bubble treatment was found to be very effective in controlling macrofouling. After five months exposure there was noticeable differences in fouling cover between the air bubble treatment (15%) and the control (64%) (Fig 4a). For the last six months of the trial there was less than 5% macrofouling cover on the air bubble treatment. In contrast the macrofouling cover on

Biofouling organisms Control Area (no bubbles)	Biofouling organisms Bubble Exposed Area
Hydroids	Hydroids
Barnacles – mostly *Amphialanus* & *Austrominius*	Barnacles – mostly *Amphibalanus* & *Austrominius*
Serpulid tube worms	
Erect Bryozoans - *Bugula* spp.	
Encrusting Bryozoans – *Watersipora* sp	
Colonial ascidians	

Table 1: Fouling organisms recorded on controls and air-bubble treatments for field trial 1

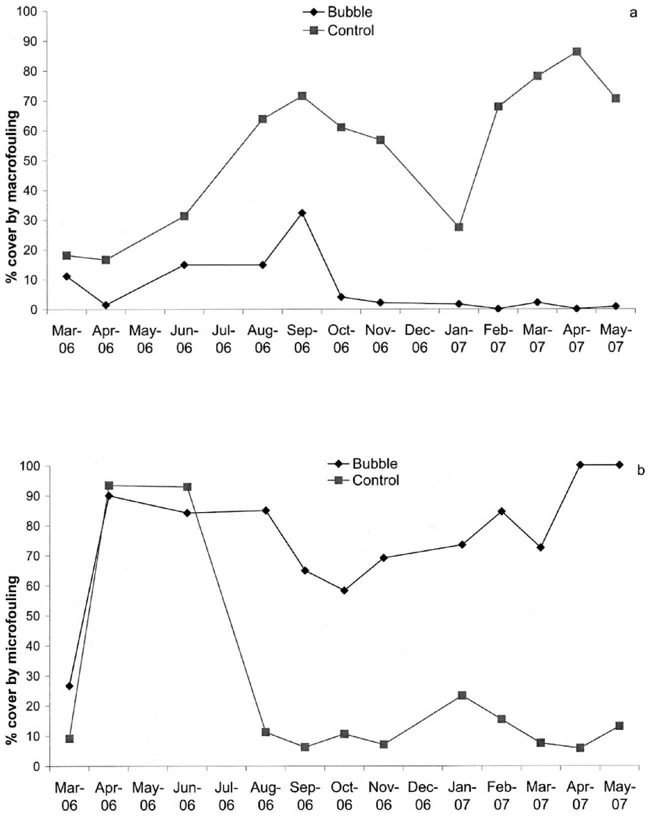

Fig 4a: Macrofouling cover over time on the air bubble treatment and the control; b) microfouling cover over time on the air bubble treatment and the control

the control increased from 20% cover to over 80% fouling cover (Fig 4a).

In contrast to macrofouling cover there was a greater covering of microfouling on the air bubble treatment compared to the control (Fig 4b). Microfouling, which is comprised predominately of slime and hydroids, was greater than 70% on the air bubble treatment for the majority of the trial (Fig 4b). The ability of the air bubble treatment to resist macrofouling ensured that there was adequate space for microfouling settlement. In contrast on the controls macrofouling quickly took over and occupied the available space on the panels for the majority of the trial (Fig 4a).

The major fouling organisms were the colonial and solitary ascidians, encrusting and erect bryozoans, tubeworms and hydroids. After six months exposure there was a greater percentage of fouling cover by all the major fouling organisms, with the exception of hydroids, on the control (Figs 5a & 6b). On the control panels fouling was dominated by colonial ascidians (29%), erect bryozoans (13%) and solitary ascidians (11%) (Fig 6). In contrast the only dominant fouling organism on the air bubble treatment was hydroids (29%) (Fig 5a & 6a).

After 12 months exposure the two major fouling organisms occurring on the air bubble treatment were an erect bryozoan (26%) and a hydroid (30%) (Fig 5b & 6c). In contrast there was a greater diversity of fouling organisms on the control, dominated by colonial ascidians (48%), tubeworms (15%), amphipod tubes (9%) and encrusting bryozoans (7%) (Fig 5b & 6d).

Importantly the thickness of the fouling cover projecting out from the panels was much higher on the controls than the air bubble treatment. As can be seen in Fig 7, the thickness of the fouling cover on the air bubble treatment is substantially reduced between Jan 2007 and Feb 2007. It

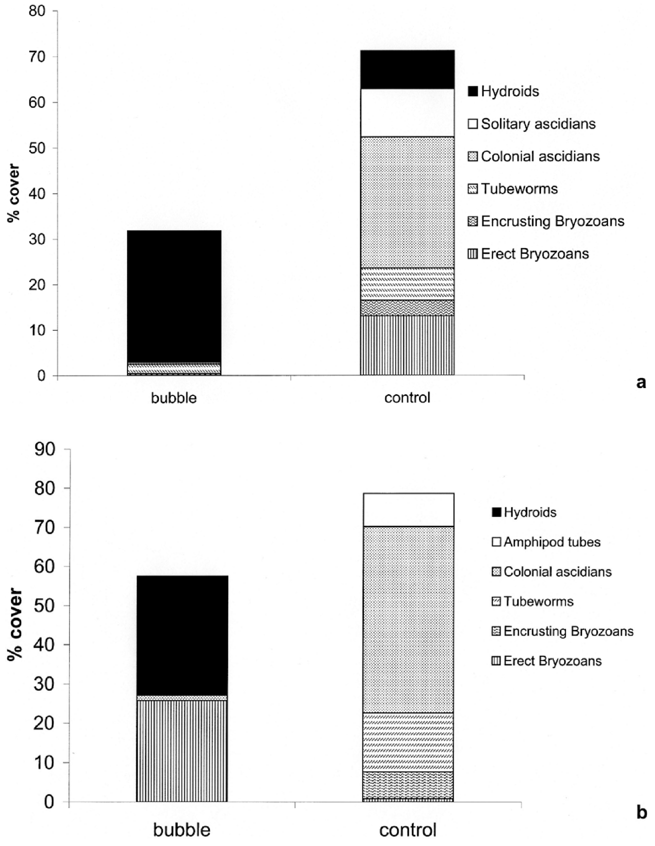

Fig 5a: Percent fouling cover by the dominant fouling organisms on the air bubble treatment and the control after six months exposure; b) Percent fouling cover by the dominant fouling organisms on the air bubble treatment and the control after 12 months exposure

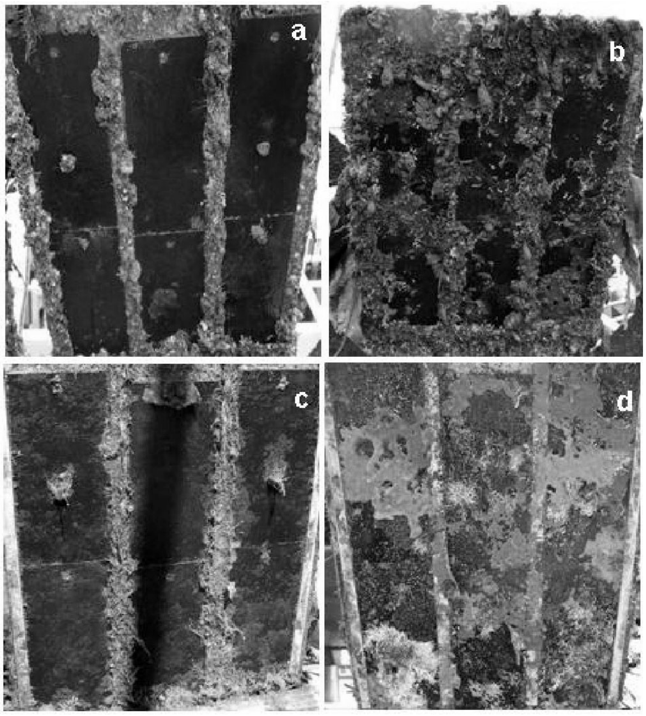

Fig 6: Comparison of fouling cover after 6 & 12 months exposure; a) bubble treatment six months; b) control six months; c) bubble treatment 12 months; d) control 12 months

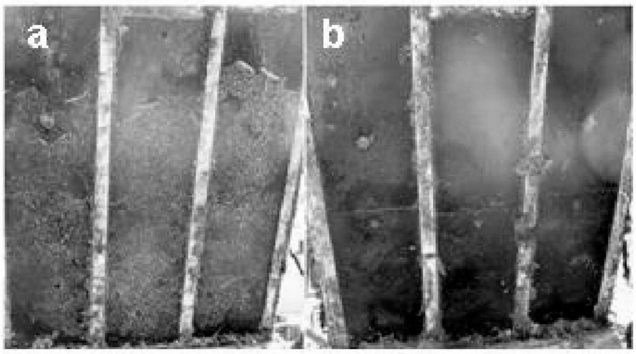

Fig 7: Changes in fouling thickness on the air bubble panels from; a) January 2007 to b) February 2007

appears that once the fouling cover reaches a certain thickness, the combination of the FRC and the air bubble treatment shears off the majority of the fouling cover leaving only a thin covering of 'runners'. By reducing the thickness of fouling cover, the penalty caused by drag will also be substantially reduced.[1] In contrast to the air bubble treatment, thickness and diversity of fouling organisms on the controls did not substantially change (Fig 6).

Field trials with ozone

Following the previous results a gaseous biocide (ozone) was added to the air to determine if this would further reduce the residual fouling on the active bubble panels and protect the spargers from fouling. After two trials each lasting one month there were no noticeable improvements in fouling control using ozone compared to air. As such the ozone trial was abandoned. Importantly, the same fouling species were observed on the treatments and controls as reported in Table 1.

Air bubble remediation

At the completion of the air bubble trial the air spargers were removed and placed on the controls to determine if the air bubbles could remediate an already fouled surface. After 10 days the fouling on the control panels were substantially reduced, particularly soft fouling organisms such as ascidians. After three weeks exposure there was a larger reduction in colonial ascidian cover, from 39% to 10%. There were small decreases in encrusting bryozoan cover and amphipod tubes (Fig 8). The decrease in cover by these macrofouling organisms created a niche which was subsequently filled by increases in hydroid and slime cover. After 10 weeks almost all the macrofouling cover had been replaced by a layer of hydroids (79%) (Fig 8).

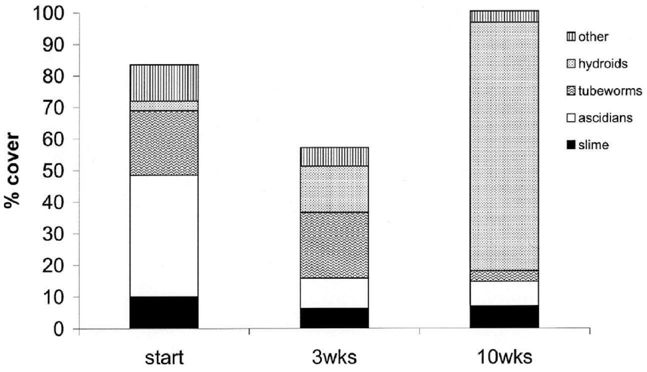

Fig 8: The composition of fouling organisms on fouled panels after periods of air bubble remediation – before air bubble treatment – after three weeks of air bubble treatment and – 10 weeks after air bubble treatment

The quick effect of the air bubbles on fouling organisms indicates that the air spargers do not need to be in continual operation. If the spargers are turned off for several days or the air bubbles do not reach the surface due to rough seas the efficiency of the air bubble treatment should not be compromised.

Vessel patch trial

The results of the vessel patch air bubble trial were largely successful. The air bubbles were continuously active over the target zone despite large changes in tides, wind and currents. The air bubbles clearly reduced the amount of fouling cover, including reduced thickness of fouling, lower species diversity and generated far less hull roughness than the other areas of the vessel not in the air bubble zone (Figs 9–11).

Fouling in the air bubble zone of the hull was limited to slime (90% cover) and other soft fouling species such as hydroids and erect bryozoans. There was very little hard

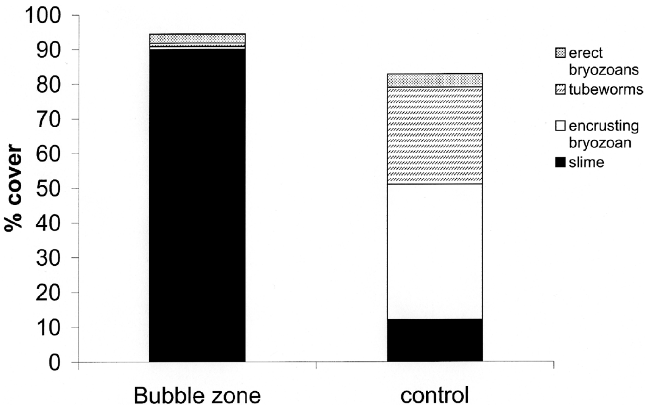

Fig 9: The composition of fouling cover on the air bubble treatment patch of the vessel and on control areas of the vessel not exposed to air bubbles

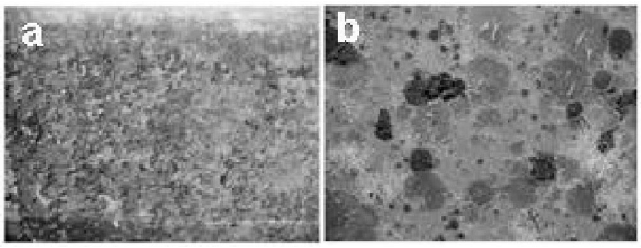

Fig 10: Fouling cover on the vessel patch trial; a) air bubble zone; b) outside air bubble zone

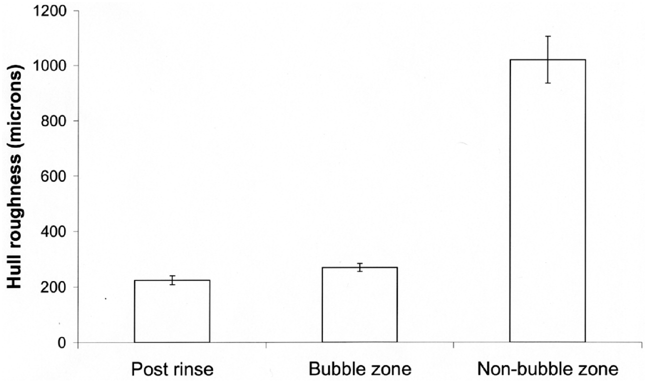

Fig 11: Average hull roughness of patches of the vessel at the conclusion of the field trial. Hull roughness measurements were taken from several sections both within and outside the air bubble zone and after the hull had been rinsed clean

calcareous fouling in the bubble zone which comprised a very light scattering of tubeworms and barnacles (< 3%) (Figs 9, 10). In contrast there was heavy calcareous fouling on other areas of the hull not in contact with air bubbles, including Spirorbid tubeworms (28%) and encrusting bryozoans (39%) (Figs 9, 10). Soft fouling on the control areas was reduced compared to the bubble zone with only 12% slime cover and 4% erect bryozoan cover.

Hull roughness measurements were taken on several sections of the hull at the completion of the trial and compared to hull roughness values for the clean vessel. It was found that areas outside that air bubble zone had substantially higher hull roughness (1019 ± 85μm) than the area of the hull exposed to air bubbles (269 ± 15μm). Hull roughness in the air bubble zone was only marginally higher than the cleaned vessels' hull roughness (224 ± 16μm) (Fig 11).

DISCUSSION

The use of air bubbles to control fouling is a novel, non-toxic technique with potentially wide application. FRC panels exposed to continuous streams of air bubbles resisted macrofouling for over 14 months. In contrast FRC panels without air bubbles were heavily fouled at times (>80%) and had a higher diversity of fouling organisms. The air bubble treatments were mainly colonised by hydroids, which produce a thin mat-like covering. Once the hydroid cover reached a certain thickness the combination of FRC and air bubbles sheared down the layer to a sparse covering of runners.

Air bubbles were also trialled on uncoated acrylic panels. Although this trial was only brief (7 weeks) significant fouling reductions were noticed compared to controls. Ozone was also trialled instead of compressed air though no added benefits were found when compared to air. Importantly, the reproducibility of bubble curtains as an antifouling technology was demonstrated by similar results being found for three separate trials over four fouling seasons.

The air spargers were also placed on the heavily fouled control surfaces at the completion of the field trial. In just three weeks significant reductions in fouling cover were observed, particularly on soft-bodied fouling organisms such as colonial ascidians. The remediation of fouled surfaces by air bubbles indicates that the air spargers do not need to be in continuous operation.

The air bubble curtains were also successfully used on a patch of a hull. The air spargers were fixed to a floating marina and were active on the hull of a vessel for several months. The area of the vessel treated with air bubbles had substantially less fouling, with only a covering of slime and hydroids. In contrast other areas of the vessel were heavily covered with tubeworms and encrusting bryozoans. The air bubble zone had far lower hull roughness than the control areas of the vessel.

This study supports the findings of Smith,[21] that air bubbles can be an effective means to reduce fouling of stationary vessels. However, this study demonstrates that the air bubble system is effective at lower flow rates and can be designed to infrastructure that is separate from the ship as such no changes to the hull are required. A provisional patent application has been lodged. In this study fouling deterrence was found over longer time periods and against a wider diversity of fouling organisms. This study also highlights the use of air bubble curtains as a complementary technology to modern foul-release coatings. However, as demonstrated in this study and by Smith,[21] air bubbles can also be effective at protecting uncoated surfaces from fouling.

The major penalty to ship hulls is the increased roughness caused by fouling.[1] Small increases in the thickness of the covering will protrude through the boundary layer and increase drag.[23] The thin covering of slime and hydroids found on the bubble rig trials is not expected to pose a significant drag penalty. The hull roughness data generated from the vessel patch trial is in good agreement with the literature. Schultz[24] lists the roughness associated with various forms of fouling (Table 2). The roughness of the patch of the vessel which was treated with air bubbles corresponds to the roughness of a deteriorated coating or light slime (300μm), in contrast the non-air bubble zones on the vessel had a mean hull roughness of >1000μm, which corresponds to small calcareous fouling[24] (Table 2).

By examining increases in a vessel shaft power an indication of increased drag and fuel consumption can be gained. For a frigate operating at 15 knots a slight slime covering is expected to increase shaft power by 11%[24] and increase fuel consumption by 6%[25] (Table 2). In contrast a vessel with calcareous fouling will have increases in shaft power from between 35–86%[24] and increases in fuel consumption of 24–92%[25] depending on the severity of the fouling (Table 2). These figures indicate that the bubble rig system could considerably reduce the ship hull fouling penalty in terms of lower shaft power for fixed speeds and reduced fuel consumption and emissions.

The mechanism behind the fouling deterrence caused by the air bubble treatment is unknown. There are three proposed mechanisms:

1. It is possible that the air bubbles simply provide a physical barrier to reaching the surface and only those fouling organisms smaller than the air bubble size can reach the surface to colonise.
2. When fouling larvae are released and are searching for a suitable place to settle they are very small (usually < 1mm) and light, as such it is possible that the turbulence created by the air bubble stream is enough to displace them from a surface.
3. Another possible mechanism is that the air bubbles create a super saturated oxygen environment which is unfavourable to potential fouling organisms.

CONCLUSIONS

Air spargers are a simple, cost effective technique to reduce fouling of submerged surfaces whilst in port. This study has demonstrated the successful deterrence of fouling organisms over an extended period of time using air bubbles. Whilst this technique has only been used on acrylic panels and a patch of a vessel, a full scale-up to cover an entire vessel whilst in port appears to be feasible. The successful application of air bubbles to control fouling has benefits not restricted to shipping, but has universal application for all marine industries.

FUTURE SCOPE

1. Air bubble spargers should be tested under tropical fouling conditions. Fouling pressure is stronger and more diverse in the tropics. The spargers need to be tested to ensure they are not fouled, thereby blocking the flow of air bubbles. The spargers could be pressure cleaned by using an occasional burst of higher velocity air flow to remove silt and slime from the spargers perforations. The ability of air bubble spargers to resist this type of fouling pressure would indicate its suitability for inception in port universally.
2. The intermittent use of the air bubble curtains needs to be trialled. It is quite possible that the air bubbles don't need to be in continuous use based on the results of the remediation trial (Fig 8). Smith[21] used air bubbles intermittently by switching off the air for 4h each day. After the 18 day trial only intermittent scattering of barnacles was observed. Using the air bubble curtains infrequently will reduce energy consumption.
3. Air bubble spargers next need to be scaled up to be active over the full length of a vessel. There may be niche areas that the air bubbles don't reach thereby requiring some spot cleaning. The behaviour of air bubble curtains on different shaped ship hulls will also need to be investigated.
4. The suitability of air bubble spargers acting on other marine coatings such as self-polishing co-polymers (SPCs) has yet to be examined. Many vessels are not coated with FRCs, hence the air bubble technique needs to be trialled against common antifouling paints. It is possible that the air bubble scouring could increase the polishing rate of the biocide. This could be beneficial if it reactivates the biocide by exposing it whilst the vessel is stationary or it could have a negative effect by over polishing the biocide and thus reducing the longevity of the coating.

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Condition	FFG-7 Roughness (μm) *(Schultz 2007)*	FFG-7 ΔSP at 15 knots *(Schultz 2007)*	> fuel consumption *(Walker & Atkins 2007)*
Newly applied antifouling biocidal coating	150	2%	-
Deteriorated coating or light slime	300	11%	~6%
Heavy slime	600	21%	12%
Small calcareous fouling	1000	35%	18–24%
Medium calcareous fouling	3000	54%	61%
Heavy calcareous fouling	10,000	86%	92%

Table 2: Summary of the effect of hull roughness caused by biofouling on shaft power and fuel consumption

sign and installation of the bubble rig prototype and DSTO colleagues Rob Zugno and Jim Dimas for assistance in the field.

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