

Review of options for in-water cleaning of ships

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Executive Summary

MAF Biosecurity New Zealand (MAFBNZ) is the division of the Ministry of Agriculture and Forestry charged with leadership of the New Zealand Biosecurity system, including preventing the introduction of marine non-indigenous species (NIS).

A main pathway for NIS is as biofouling on vessel hulls, and at present there is no management for this pathway. This report has been commissioned to review worldwide underwater hull cleaning practices and systems to determine if hull cleaning systems that can contain and capture marine fouling debris as it is removed from the hull exist, or are in development.

A review of marine fouling and its effects on ship propulsive fuel use is conducted, as well as discussions of present and future toxic and non-toxic antifouling paints. The shipyard application and removal of underwater hull coatings is reviewed, and the environmental aspects of ship hull coatings are discussed.

Underwater hull cleaning is commonly used to remove marine fouling and restore the ships' fuel efficiency. This process may also release foreign marine organisms into local receiving waters. This report discusses the effectiveness of the hull cleaning technologies, the extent to which biological and chemical contaminants are contained (or could be contained) and prevented from returning to the environment. Technologies for cleaning both the main hull of the vessel and niche areas (e.g. sea chests, bow thrusters, propellers and propeller shafts) are discussed, as well as the practical considerations for using the technologies.

A worldwide review was conducted of any potential technology that showed promise for a contained underwater hull cleaning process. Four systems that have been built have been identified, 1) the U.S. Navy Advanced Hull Cleaning System (AHCS), 2) the modified Scamp from Seaward Marine Services, 3) the HISMAR system based in the UK, and 4) CleanROV, a Norwegian system. The AHCS, which is the only system to incorporate a water treatment system, is undergoing field testing at present. The Seaward marine system has been dismantled; the HISMAR system is a concept in early stages of development and is awaiting funding. The CleanROV system is operational, but does not include water treatment or the ability to remove or process large amounts of fouling. In addition, UMC, a UK based company, claims to be developing a capture system for their Mini-Pamper cleaning vehicle, and does have a capture system for propeller cleaning. The system that is closest to operational and that fulfils most of the need for contained hull cleaning is the U.S. Navy AHCS. This is not presently a commercially available system. There is also an Australian system, HST, using hot water that is claimed to disrupt algae and biofilms before they allow higher fouling forms to colonise the surface.

A biofouling sampling program has recently been conducted in New Zealand. The results from this study, when published, should help determine the type and frequency of marine NIS on ship hulls entering New Zealand. Also, the U.S. Navy AHCS should be evaluated for use in NZ, and the other contained cleaning efforts monitored.

It is likely that future regulatory actions governing discharges from underwater hull cleaning, should they occur, would give the commercial marine technology sector the incentive to invest capital in the development of contained underwater hull cleaning and water treatment systems.

1. Introduction

MAF Biosecurity New Zealand (MAFBNZ) is the division of the Ministry of Agriculture and Forestry charged with leadership of the New Zealand biosecurity system. It encompasses facilitating international trade, protecting the health of New Zealanders and ensuring the welfare of the environment, flora and fauna, marine life and Maori resources.

A main pathway for non-indigenous species (NIS) is as biofouling on vessel hulls and at present there is no agreed approach to management for this pathway. The New Zealand government is working through the Marine Environment Protection Committee (MEPC) of the UN International Maritime Organization (IMO) to examine possible guidance or regulation for minimising the transfer of NIS through biofouling on ships.

As part of this work, MAFBNZ intends to provide a scoping report to an IMO working group canvassing the options available, or meriting further investigation and development, for in-water cleaning of ships. This will complement work the Department of Agriculture, Fisheries and Forestry (DAFF) (Australia) is conducting examining the cost/benefit of in-water cleaning under different scenarios, and at the availability of non-cleaning treatments.

Shipping operators have long been interested in the prevention of biofouling build-up on open hull areas to maintain laminar flow over the hull when underway and reduce propulsive fuel costs. There has also been much interest in extending the period before re-application of antifouling coatings is required, for example by exposure of new active layers of the antifouling coat by hull cleaning. Management of biofouling on ships' hulls and niche areas to prevent the build up of biofouling, or to extend the effective life of antifouling coatings, may require occasional cleaning of the hull between the (typically) five yearly dry docking that occurs for hull survey and repainting.

To minimise the risk of the invasion of marine NIS, in-water cleaning techniques are required that are able to capture or kill the biological material removed from the vessel. MAFBNZ's purpose overall is to determine the extent to which current or proposed cleaning techniques or technologies can be used to prevent the build up of biofouling on international vessels, reduce global transfer of NIS, and to aid the future development of useful solutions.

The purpose of this report is to review in-water cleaning techniques and technologies that are currently available or under development and their applicability to managing the risks of transfer of marine NIS. The review will consider:

- effectiveness of the technologies;
- the extent to which biological and chemical contaminants are contained (or could be contained) and prevented from returning to the environment;
- technologies available for both the main hull of the vessel and all niche areas (e.g. sea chests, bow thrusters, propellers and propeller shafts);
- the practical considerations for using the technology (e.g. availability, cost, operational requirements, health and safety).

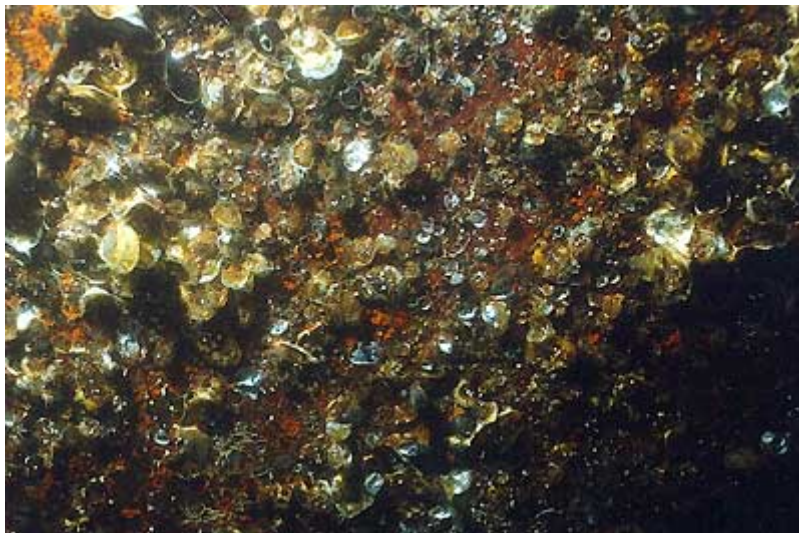
2. Background

2.1 BRIEF REVIEW OF MARINE FOULING AND ITS CHARACTERISTICS

All world shipping, both commercial and military, depends on antifouling coatings to minimise the accumulation of marine fouling on underwater hulls. This function is critical to reducing hydrodynamic drag of the hulls and to maintaining propulsive fuel efficiency of the ship.

The accretion of marine fouling can be highly variable, depending on geographical location, time of year, and seasonal variations in weather, such as the "El Nino" phenomenon. In general, fouling flourishes during warmer months and diminishes in cooler months. There are many additional variables, such as the availability of nutrients to support the fouling communities. Classic (Woods Hole Oceanographic Institution, 1952) and modern (Hellio & Yebra, 2009) reviews of marine fouling are available. In general, the longer a ship stays pier side, the more likely it is to accumulate fouling. Figure 1 shows marine fouling on a ship hull.

Figure 1 Marine fouling on ship hull



Typically, most commercial ships operate the majority of the time, while naval vessels may spend long periods of time pier-side. For example, the general operating cycle for the U.S. Navy vessels is between 40-60 percent pier-side with the rest at sea. Commercial ships may be at sea 85 percent or more as they only generate revenue when delivering cargoes.

Typically, there is a progression of attachment of marine organisms to a painted hull. The toxicant acts as a deterrent to the attachment of higher forms such as barnacles and tubeworms, but will usually allow attachment of biofilms and algae to the hull within days or weeks of launching with fresh paint. As the antifouling paint ages and begins to lose effectiveness, calcareous forms will begin to appear, typically on sharp edges such as weld beads, chines, sea chests and niche areas. This is then followed by a more general infestation, spreading beyond edges onto the flats of the ship hull. In addition, the propeller, which is typically not coated due to the difficulty in adhering paint to bronze, and to the hydrodynamic forces the propeller encounters will foul rapidly with calcareous forms.

The many variables of marine fouling accumulation will determine the mix of species that will inhabit the hull. Ships engaged solely in coastal trading will likely have only organisms

from that region on the hull. Ships that engage in deep water voyages will have a higher likelihood of carrying foreign fouling organisms long distances, resulting in the potential of NIS invading foreign waters. There are many instances of this occurring in all major shipping ports of the world.

2.2 EFFECTS OF MARINE FOULING ON SHIP OPERATIONS

Marine fouling has an immediate and potentially severe effect on ship performance. Any roughness on a ship hull that disrupts the laminar flow along the hull will produce drag. When a ship hull has been recently serviced, undergone complete sandblasting and painting, the hull will be as smooth as possible. Entering service, the hull will gradually roughen with time as a function of paint erosion and damage, fouling accumulation and corrosion. This roughness will increase drag and correspondingly propulsive fuel consumption. Many studies have been conducted worldwide that have identified roughness increases and marine fouling as the cause of increased fuel consumption (Bohlander 1991). The magnitude of additional fuel use is quite variable, depending on the amount of fouling, the shape of the hull, and the speed at which the ship operates. Fuel penalties in the range of 5 percent to 25 percent have been observed on U.S. Navy ships during sea trials (Hundley et al. 1980).

Figure 2 Power trials before and after hull cleaning showing effects of removal of marine fouling from U.S. Navy ship

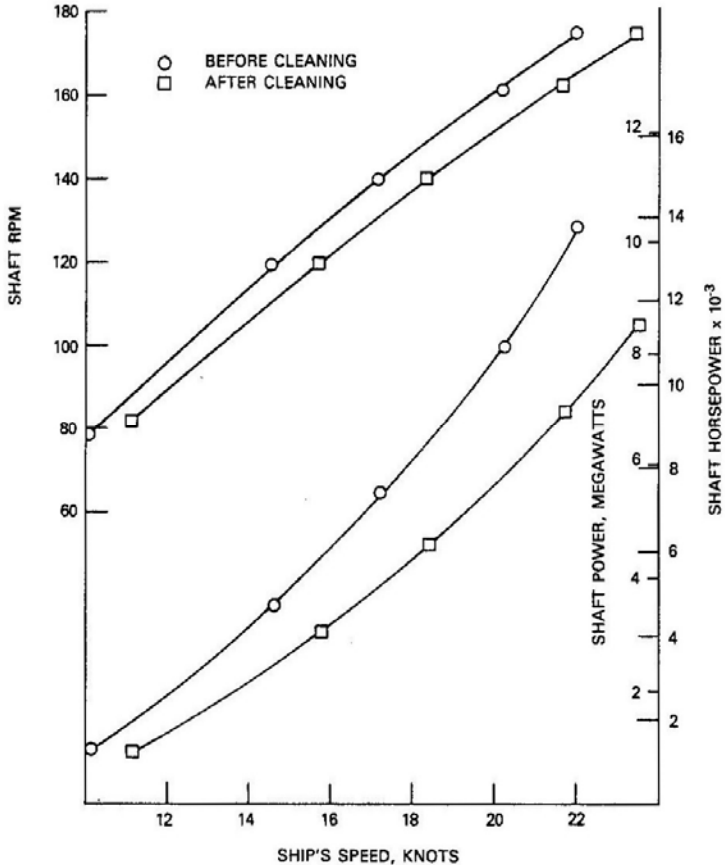


Figure 2 shows before and after power consumption curves showing the effects of removal of hull fouling on propulsive power consumption. Bohlander and Montemaraono (1997) provide an overview of fouling effects on Naval operations.

Commercial ships may have similar fuel penalties, although it may be expected that commercial shipping, which spends more time at sea than military shipping, should have less fouling and a lesser fuel penalty.

The calcareous fouling that accumulates on propellers, which in most ships are left un-coated, has a severe effect on propulsive fuel consumption. Frequent propeller cleaning is essential to maintaining efficient ship operations.

3. Review of antifouling paint technology

The vast majority of modern antifouling (AF) paints use some form of cuprous oxide as the primary toxicant to discourage the settlement of marine fouling. There is a long history of active ingredients used in AF coatings, ranging from toxic heavy metals to organic pesticides, tri-organotin compounds and even hot pepper. While there have been many toxicants used, most modern paints use cuprous oxide either alone or in combination with organic pesticides (co-biocides), in an ablative paint matrix designed for maximum service life. A recent addition to this category is copolymer ablative paints. These coatings claim to have a higher degree of ablation control, thus prolonging the service life of the paints.

Ablative paints are designed to slowly wear away using a combination of hydrolysis and mechanical erosion. The active toxicant ingredients in the paint must be able to leach into the water to be effective, and as the paint ages, this leaching slows down due to depletion of the toxicant near the surface of the paint. Thus, the ablative process aids the performance of the AF paint by allowing fresh toxicant to be exposed to seawater, which prolongs the life of the paint. The ablative process also can dislodge fouling that is attached to the paint as the ship moves through the water. Underwater hull cleaning can also remove measurable amounts of AF paint (Whittaker & Wimmer 1997).

It has long been a goal of paint companies to produce an antifouling paint that does not contain toxic ingredients. There are several benefits to such a coating, including relaxed environmental regulation for use and disposal, no impact on the local marine environment from the leaching of toxic ingredients into the water column, reduced hazards to the shipyard workers applying and removing the paints and less generation of hazardous materials during application and removal. While there are several approaches to non toxic coatings, the primary one in use today is silicone based polymers. These materials when applied to ship hulls produce a surface that discourages the settling and accumulation of marine fouling. The mechanism is to create a low surface energy coating that releases marine fouling under the influence of ship movement. This family of coatings is referred to as foul release paints. Coating manufacturers claim propulsive fuel efficiencies of 3-11 percent for using these paints. These improvements can be realised if the ships using the products cruise at speeds ranging from 10-18 knots, and spend relatively little time pier side. However, this process may not be totally effective, and these paints may still require hull cleaning. There is a possibility that the cleaning process may damage the silicone paints, allowing increased fouling growth.

There are several manufacturers of foul release paints, with a variety of products on the market. All share the characteristic of generally allowing marine fouling to attach to the coating while the ship is pier side, then claiming the fouling will detach with ship movement. However, it is also possible that ships using foul release paints may transfer NIS from one location to another if the paint does not completely self clean. There is likely to be variability in performance for these products, and while they are in regular commercial use, it will take additional time to get a clear indication of the benefits and operating characteristics of these materials as well as their potential for NIS transmission.

3.1 NON-INDIGENOUS SPECIES TRANSPORT POTENTIAL OF TOXIC ANTIFOULING PAINTS

AF paints containing toxicants will have varying success in preventing the accumulation of marine fouling. The many variables discussed above will apply to their antifouling performance. Ablative paints, while more effective than hard AF paints, may still allow marine fouling to attach, especially in niche areas such as sea chests, thruster tunnels, rudder areas, and around shafts and struts. In addition, keel block areas, which are not painted during overhauls, will support marine fouling growth. Also, as AF paints age, they become less effective. Extended time pier-side can also allow fouling growth, especially if it occurs during summer, and necessitate hull cleaning. Ablative AF paints will decrease in thickness with age and may have reduced effectiveness as the amount of cuprous oxide in the paint diminishes.

3.2 NON-INDIGENOUS SPECIES TRANSPORT POTENTIAL OF NON TOXIC FOUL RELEASE ANTIFOULING PAINTS

The silicone based antifouling coatings have begun to establish a market in commercial shipping fleets, primarily with cruise ships and fast container ships, as these vessels have operational profiles that are suitable for the use of foul release paints. These paints perform best when the ship spends the majority of its time underway, as this allows the fouling to be removed by hydrodynamic forces as the ship moves through the water. If these ships were to spend time pier-side, particularly during warmer months, fouling would quickly accumulate. When the ship resumes operation, the coating is designed to shed the marine fouling as it goes to sea. However, it is possible that not all fouling would be removed, allowing some growth to remain and possibly be transported to another country. Trials on a ship coated with silicone paint where power was measured before and after hull cleaning show an improvement in power of 6 to 9 percent after hull cleaning (Hundley & Bohlander 1999). Underwater inspections will be critical in determining if foul release paints can transport fouling materials across oceans.

3.3 SHIPYARD APPLICATION AND REMOVAL OF ANTIFOULING PAINT

Antifouling paints are an essential component of the underwater hull coating system. All ships require periodic dry docking to maintain the underwater hull. Commercial ships usually dock every 5 years. This docking interval will be specified by various insurance agencies, international regulatory bodies, and classification societies or national agencies such as Lloyds of London, DNV, and the U.S. Coast Guard. These dry dockings allow inspection of hull and structural integrity, determine the corrosion condition of the ship, and allow for renewal of the underwater hull paint system.

After old paint is removed from a steel ship hull, typically with either abrasive blasting or ultra high pressure water, the hull is inspected for corrosion condition and any necessary repairs are done. The ship is then coated, typically with two coats of an anticorrosive (AC) paint. Modified epoxies are the coating of choice for the majority of AC applications. This is followed by two or three coats of antifouling (AF) paint, depending on the time of service desired. AF paints may be the older technology hard AF, the ablative AF or the newer co-polymer co-biocide AF paints.

There are many environmental and human health issues associated with dry-docking a ship, removing the old hull paint and applying new coatings. These include:

- the generation of large amounts of spent abrasive blasting materials contaminated with e.g. cuprous oxide AF paint;

- the possible hazard of dust associated with blasting;
- the generation of large volumes of waste water if ultra high pressure water is used for removal;
- the possibility of rain water leaching heavy metals and contaminants from blasting grit in the dock;
- the over-spray that typically results from application of the AC and the AF paints;
- human health concerns from dust, solvents and chemicals for the workforce;
- potential release of NIS into the surrounding marine environment if effective waste treatment is not in place.

Many dry-docks may be antiquated and unable to capture and contain liquid waste generated during their use, and may require expensive modifications to effectively manage these issues.

The degree of containment required to prevent toxic materials from being released into the marine and terrestrial environments is a function of local and national regulations. These factors significantly influence the cost of paint removal and application, and may inadvertently encourage shipping companies and navies to extend docking cycles whenever possible.

3.4 TRENDS IN CURRENT ANTIFOULING PAINT TECHNOLOGY

The technology of antifouling paints is continually evolving. Early paints focused on the use of increasingly toxic ingredients in the attempt to prevent all types of marine fouling. Unfortunately, they also had the potential to effect non-target species. Environmental awareness has led to research into alternatives to the earlier and current heavy metal based toxicants. International, federal and state policies on the prevention of marine fouling and the management of fouling wastes are available (e.g. Savarese 2005 and ANZECC 2009).

Recent trends in toxicant-containing AF paint development have been primarily in the area of reducing cuprous oxide content, combining cuprous oxide with various organic pesticides, and the development of co-polymeric resins that serve to control the ablation and active agent release from AF paints. There is a large body of knowledge on copper paints that is regularly discussed by various working groups e.g. in the US. Callow & Callow (2002) also discuss AF technology.

A Technical Seminar on Antifouling Paint Highlights: Regulatory, Technology, and Performance Testing, sponsored by ASTM (American Society for Testing and Materials) Committee D01 on Paint and Related Coatings, Materials, and Applications, will be held Tuesday, June 23, 2009. This seminar will summarise the current state of the technology, including U.S. Navy efforts. The presentations will be available on from ASTM after July 2009.

Efforts in non-toxic AF coatings concentrate on the use of silicone-based paints that attempt to design a surface that provides poor adhesion for marine fouling attachment. There have also been derivative formulations using silicone topcoats to inhibit fouling adhesion (U.S. Navy Research Laboratory 2000). Modification of surfaces is another approach to AF technology which is being pursued (AMBIO 2009).

3.5 DISCUSSION OF U.S. ANTIFOULING PAINT TECHNOLOGY FUTURE RESEARCH

USDOD DARPA Marine Fouling Prevention Efforts: The U.S. Government agency Defense Advanced Research Projects Agency (DARPA) as described on their website (<http://www.darpa.mil/index.html>) is the central research and development organisation for the U.S. Department of Defense. DARPA's mission is to maintain the technological superiority of the U.S. military and prevent technological surprise from harming national security. They fund researchers in industry, universities, government laboratories and elsewhere to conduct high-risk, high-reward research and the development of projects that will benefit U.S. National Security.

DARPA recently announced a new program initiative to develop a new AF coating to replace ablative and toxic AF paints with ones that contain no toxicants and have no negative effects on the marine environment. This ambitious program, called Dynamic Prevention of Biofouling (DyPoB), which is now (June 2009) evaluating proposals, has the potential to develop a new class of AF materials that would be environmentally benign (DARPA 2009). This initiative is starting in mid-2009, and has two 24 month phases planned for the program.

U.S. Office of Naval Research Marine Fouling Control Efforts: The U.S. Navy Office of Naval Research (ONR) has long invested in improvements in AF technology with the goal of reducing or eliminating the use of toxic compounds. Their current research efforts in the antifouling area take the following approach (McElvany et al. 2009):

- Improved understanding of the biological, chemical and physical processes important in organism settlement and attachment.
- Multi-disciplinary approach: Integrated coatings development; lab testing and field testing of coatings
- Coatings approaches: Foul-release; reduced settlement (complex/patterned surfaces); tethered biocides.
- Development of robotic Hull Bug (bio-inspired underwater grooming): An un-tethered small (in size and cost) remotely operated vehicle (ROV) platform with the ability to disrupt early fouling biofilms to prevent the settlement of larger organisms.

An additional ONR approach concerns the biology component of AF technology (Chrisey 2009). This program is attempting to study the bio-adhesion of marine organisms with hopes of finding methods of disrupting settlement and attachment of these organisms.

3.6 IMO ANTIFOULING PAINT ACTIONS

The IMO has been active in studying and regulating AF coatings for some time. Their latest actions concern AF paints that contain tri-butyl tin (TBT) compounds. After several years of study and debate, IMO adopted the International Convention on the Control of Harmful Antifouling Systems of Ships which entered into force in September 2008 (International Convention on the Control of Harmful Antifouling Systems on Ships, 2001). This effectively constitutes a worldwide ban on AF paints containing TBT. These paints must either be removed and replaced, or over-coated with AF that does not contain TBT.

4. Underwater ship hull husbandry and in-water cleaning technologies

The vast majority of ships coated with antifouling paints will develop accumulations of marine fouling during their service life. This has a severe impact on propulsive fuel consumption due to an increase in hydrodynamic drag caused by fouling.

Ships normally will not be dry docked to remove fouling. This is cost and time prohibitive. Commercial shipping uses hull cleaning on an as-needed basis to maintain efficient propulsive fuel use. Since commercial ships need to be operational to generate revenue, hull cleanings are typically done during loading and unloading at commercial ports. Hull cleaning companies have facilities in most major ports worldwide to service the shipping industry.

Underwater hull cleaning methods (hull husbandry) have been developed to remove marine fouling from ships during their service period between dry-docking. The majority of these methods use diver-operated machines fitted with rotating brushes. These systems can be used on steel, aluminum or composite hulls. Their limiting factor is curvature of the hull; most larger cleaning devices can not be used on smaller ships with a radius under 10 feet (3m) or on yachts due to their small area and curvatures.

There are several designs of underwater hull cleaning machines in use world wide. The larger multi-brush machines include the Scamp (Figure 3), Mini-Pamper (Figure 4), Brush Kart (Figure 5) and other designs.

Figure 3 Scamp Underwater Hull Cleaning Multi Brush Vehicle

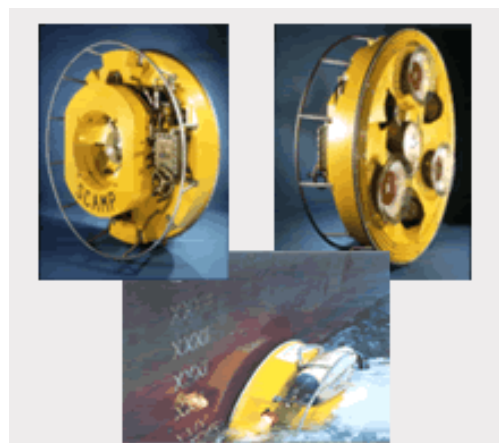


Figure 4 Mini-Pamper Multi Brush Hull Cleaning Vehicle from UMC



Figure 5 Brush-Kart Multi Brush Vehicle



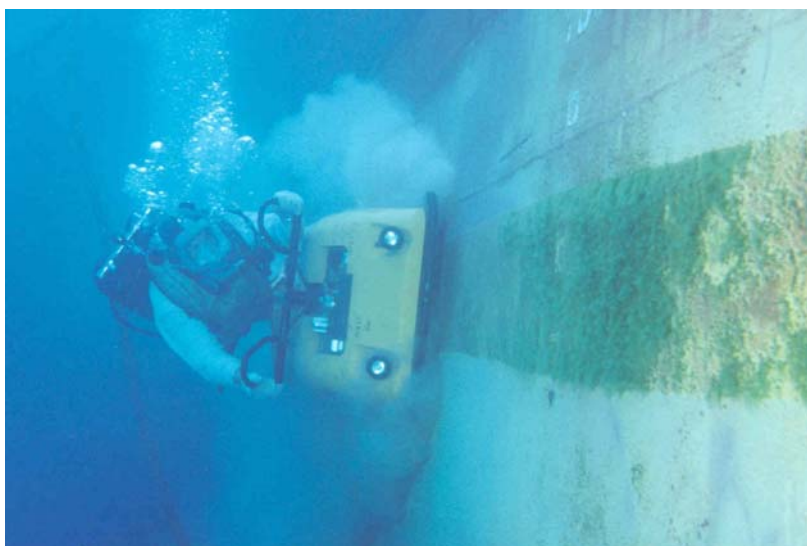
These multi-brush machines are supplemented by single brush machines that divers use for cleaning areas of higher radius that the multi-brush machines cannot reach, for running gear (propellers, propeller struts, rudders), for bilge keel areas and for sea chests (openings in the hull that draw in and discharge cooling water). High pressure water jet wands are also used to clean fouling from hard to reach areas.

Multi-brush machines have wheels that drive and steer the unit along the hull, and also serve to maintain a constant height for the cleaning brushes. The machine is placed on the hull by divers, and adheres to the hull either by the use of an impeller creating suction against the hull or by the vortex action of the rotating brushes.

It is good practice for ships, both military and commercial, to monitor their propulsive power use to determine if the hydrodynamic drag from fouling has increased propulsive fuel use. This can be done in a variety of ways, including on-board instrumentation for measuring speed over ground, shaft RPM, shaft horsepower, and other parameters that assist the ship's engineer in determining economical running conditions. The first indication a ship requires hull cleaning is a reduction in distance traveled with a constant RPM, or an increase in RPM required to reach a given speed. These changes should alert the ship that an inspection of the hull is warranted.

The general process for underwater hull cleaning is to conduct a pre-cleaning inspection with divers or small ROVs. This determines the need for cleaning and also the choice of brush type. It is very important to choose the least aggressive cleaning brush that will effectively remove the fouling. This is important to avoid excessive paint wear that will shorten the service life of the AF paint and to reduce the amount of copper discharged into the water from the cleaning process. Once the fouling is deemed sufficient to warrant a hull cleaning, the multi-brush vehicle is deployed into the water and commences cleaning the hull by making long parallel passes along the length of the ship (Figure 6).

Figure 6 Mini-Pamper demonstrating the parallel cleaning technique



There are several kinds of brushes available, including soft plastic bristle brushes, stiffer polymer bristle brushes, composite brushes with both plastic and metal bristles, and all metal bristle brushes for propeller cleaning and polishing. The U.S. Navy list of brushes for different machines and fouling conditions is available (<http://www.supsalv.org/webApp/AppBrush/AppBrushes.asp>). The varieties of brushes are designed for varying fouling conditions. It is also very important to clean propellers to maintain fuel efficiency. Propellers are usually constructed of nickel aluminum bronze, and are generally not coated to repel fouling due to the difficulty of paint adhesion to bronze and to hydrodynamic forces such as cavitation erosion. Thus they can foul very quickly and will have a very negative effect on fuel consumption.

4.1 HULL CLEANING METHODOLOGIES AND PROCESSES

The majority of hull cleaning machines use rotating brushes, but there are also devices that use high pressure water to remove fouling. In addition, high pressure water is used with diver operated wands to blast off fouling from sea chest grates and other underwater components.

Underwater hull cleaning can be a very effective way to remove marine fouling. This process also will remove some AF paint. A comprehensive discussion of leaching from AF paints was prepared by the U.S. Environmental Protection Agency (EPA) in 2003 (Naval Sea Systems Command & Office of Water, 2003).

This removal of paint also serves to refresh the surface of the AF paint, which may be depleted in copper due to leaching, and allows the paint to perform for a longer period of time. Earlier hard AF paints required the abrasive cleaning process to extend their service life

beyond 18-24 months, but modern ablative AF paints can maintain good service if the ship spends most of its time at sea, as most commercial ships should do. Military ships may have more fouling accumulation due to lesser time at sea than commercial ships. Of course, if commercial ships are inactive due to economic conditions, they are likely to foul quicker and to need a hull cleaning prior to re-entering service.

The periodicity of underwater hull cleaning is determined by the effectiveness of the AF paint. The many factors that influence performance may result in widely differing periodicities of hull cleaning. The initial performance of copper AF paints is usually very good, as immediately after undocking, the paint has the highest release rate of cupric ions into the water. It usually takes several months for this rate to fall to a steady state value. At that point, the factors of time at sea, season of the year, and geographical area will determine the fouling rate of any given ship.

Cleaning the niche areas of the hull may present a challenge. Most niche areas are difficult to properly prepare and coat even when the ship is in dry dock. This is due to tight clearances for surface preparation (sandblasting or hand tool preparation) and paint application. This results in poor paint quality, and premature fouling of these areas. In addition ablative paints can do poorly due to lack of water flow in niche areas. Hard AF paints may offer benefits if used in these areas. Some niche areas can be reached in-water, but many are difficult or impossible to reach by divers with cleaning tools. For example, the underside of the bilge keel (rolling keel), while challenging to reach, is usually straightforward to clean using single brush diver operated units. However areas such as above the rudder and the inside of sea chest intakes and discharges and thruster tunnels may be difficult or impossible to reach. Some areas may require the underwater removal of sea chest gratings, which is time consuming and sometimes difficult due to corroded bolts, or to designs that make no provisions for grate removal by divers. High pressure water wands may be able to reach some areas, but also can have the negative consequence of damaging the AF paint due to the high water flow it takes to remove fouling. The use of hand scrapers can also damage the paint system, resulting in corrosion and fouling.

There is a novel hull cleaning system called HST by an Australian company called Commercial Diving Services Pty Ltd. This system uses a containment device attached to the hull that pumps hot salt water so it contacts the marine fouling. It is designed for killing algae and grasses. They have also discussed creating custom enclosures that could expose niche areas to hot water and kill fouling in those areas.

4.2 WATER QUALITY IMPLICATIONS OF UNDERWATER HULL CLEANING

The underwater hull cleaning process typically uses a multi-brush vehicle to clean fouling from the ship hull, which is coated with an AF paint containing a biocide such as cuprous oxide. The choice of brush is dictated by the severity of the fouling. While the least aggressive brush that is able to remove the fouling should be used, as noted above, it is likely that hull cleaning will remove a finite amount of AF paint. The amount removed will be a function of the type of paint on the hull (hard, ablative, copolymer), the age of the paint, the severity of the fouling, the type of brush and cleaning machine used, and the skill of the operator. Some studies have indicated from 0.5 mils (thousands of an inch) up to 3 mils of paint can be removed by hull cleaning brushes (Ingle 2006). It should not be assumed that the removed paint has the as-manufactured amount of biocide in it, as it is likely that the paint on the surface of the hull (the leached layer) has been depleted of the biocide during service.

Underwater hull cleaning is usually quite effective in removing marine fouling from intact AF painted surfaces. Since the purpose of underwater hull cleaning is to remove marine fouling, there will be a discharge of biological materials into the water column from the cleaning process. This will consist of biofilms, algae, multi-cellular forms, and various higher forms such as barnacles, tubeworms, bryozoans, oysters, and possibly many others. The cleaning process will disrupt the organisms, crushing shells and biological material and spreading it out into the harbor. It is possible that some organisms can survive this process, and others may spread incipient juvenile forms during the cleaning process. Thus, lacking any detailed analysis of the hull cleaning effluent stream, it should be considered a possible source of NIS.

If the hull cleaning process is taking place on a hull painted with silicone non-toxic foul release paint, there is also a potential for NIS transport. Specialised equipment and techniques are required to avoid damaging the silicone paints. If the paint has performed in an ideal fashion, there should be little biological material on the hull surface exposed to hydrodynamic flow. However, should the paint be aging, or a species resistant to release from water flow has become established, there could be fouling remaining on the hull. In addition, niche areas with little or no water flow will likely have accumulated marine fouling. The hull cleaning process will likely discharge hull fouling into the harbor when these paints are cleaned. A comprehensive review of hull fouling and NIS transport was conducted by the University of California (Gonzales & Johnson (2005), who produced a report on managing hull transport of invasive species, which discusses this issue and identifies international rules currently in effect.

4.3 EXAMPLE OF HULL CLEANING DOCUMENTS AND PRACTICES U.S. NAVY

The U.S. Navy has been conducting underwater hull cleaning since about 1978. The purpose of the cleanings is to restore propulsive fuel efficiency. The U.S. Navy hull cleaning procedures are regulated by a document known as Naval Ships Technical Manual (NSTM) Ch 081, "Waterborne Underwater Cleaning of Navy Ships" (U.S. Navy 2006) which details the hull inspection and cleaning process, provides visual comparison and tables for identifying fouling severity, and lists approved cleaning equipment and brushes. The U.S. Navy conducts periodic diver inspections of their hulls to determine the fouling condition of the ship. The fouling is rated from 0 to 100 in units of 10, using comparison photographs. Hull cleaning is initiated with a fouling rating of 40 or greater, which is the appearance of calcareous fouling on edges and weld beads.

Currently, the discharges from hull cleaning in the USA fall under the Clean Water Act, which is administered by the various states. This results in numerous regulations that may differ in different states. The U.S. EPA is working with the U.S. Naval Sea Systems Command (NAVSEA) on a Uniform National Discharge Standards (UNDS) program. UNDS will create rules to govern numerous aqueous discharges from the Army, Navy, Military Sealift Command, and Coast Guard that would be standardised across the country (<http://unds.bah.com/default.htm>).

4.4 CURRENT RESEARCH AND DEVELOPMENT IN CONTAINED UNDERWATER HULL CLEANING

The standard underwater hull cleaning tools, both multi-brush and single brush tools, have no inherent capability to contain the materials removed from the hull during the cleaning process. These materials consist of paint particulate matter abraded from the AF coatings and a mix of biological material from the marine fouling on the hull. These particulate materials are ejected into the water column (Figure 7).

Figure 7 Scamp hull cleaning showing discharge of marine fouling



Typically, hull cleaning is quite effective at removing marine fouling from AF paints, but the effluent stream from cleaning is quite difficult to capture.

Several prominent underwater hull cleaning vendors were contacted in the USA, UK, Norway, and Singapore (Table 1). Most were aware of the concept of contained underwater hull cleaning, but were reluctant to invest capital in capture technology without a customer needing this service, or without regulatory drivers requiring containment. The systems where information was available are described in some detail below.

Table 1. List of individuals and corporations contacted during the preparation of this report

Company	POC	Location	Contact Information
Oceaneering, Inc	Larry Kary	Hanover, Md. USA	KARL@oceaneering.com
Seaward Marine Services	Cecil Accord	Norfolk, Va. USA	Cecil@Seaward-Marine.com
UTC CleanHull AS	Alan Trevarthen Endre Eidsvik	Southampton, UK Norway	alantrevarthen@umc.co.uk endre.eidsvik@cleanhull.no
Commercial Diving Services Pty Ltd	Keith Johnson	Australia	info@commercialdiving.com.au
Underwater Shipcare	Paul P Barrie	Singapore	divers@uwsc.com.sg
U.S. Navy (NAVSEA)	Tom McCue	Washington, DC	thomas.mccue@navy.mil
Safinah Ltd	Raouf Kattan	Northumberland, UK	enquiries@safinah.co.uk

5. Review of systems under development

Five systems were evaluated in detail for this report: 1) the Advanced Hull Cleaning System (AHCS); 2) the Seaward Marine Services modified Scamp; 3) the CleanROV system; 4) the HISMAR system; and 5) UMC International Plc.

5.1 U.S. NAVY ADVANCED HULL CLEANING SYSTEM (AHCS) SYSTEM

The U.S. Navy has developed a prototype multi-brush hull cleaning system that captures the debris generated from hull cleaning and transports it to the pier for processing in a mobile treatment trailer. Oceaneering, Inc of Hanover, Maryland, USA developed the system under contract from the Naval Sea Systems Command. This system, known as the Advanced Hull Cleaning System (AHCS) was developed primarily to reduce the amount of copper discharged during hull cleaning of U.S. Navy ships. It was not specifically developed to process marine fouling, although fouling is contained and processed by the system. See Appendix A for a description of the system.

The AHCS is contained on two 48' trailers; one for the mobile support unit and advanced hull cleaning vehicle (AHCV), and one for the effluent wastewater management unit.

The AHCV (Figure 8), has three cleaning brushes mounted on an articulated deck forward of the main body of the vehicle.

Figure 8 U.S. Navy Advanced Hull Cleaning Vehicle



The brushes are mounted inside an articulated shroud which is connected to a pump that pulls in seawater around the brushes and thus captures the debris generated by cleaning. The main body of the vehicle has the drive and steering wheels and diver controls. The captured effluent is re-circulated to minimise total flow and transported up a hose to the pier to a treatment trailer.

The AHCV (Model MK-1C) is one critical component of the integrated AHCS. This diver operated vehicle removes the marine growth from the hull and reduces heavy metals and marine fouling discharges into the environment by capturing the debris and transporting the effluent to the pier side waste management unit prior to discharge to the sewer. A hand held single brush contained cleaning unit is not presently available for this system, although a pre-production prototype has previously been evaluated.

The effluent waste management unit is the second component of the integrated AHCS. Its function is to process the AHCV wastewater via primary settling, chemical precipitation,

ACTIFLO® sand ballasted clarification, and sludge de-watering. The trailer is equipped with a programmable logic controller, human machine interface, diesel powered generator, air compressor, hydraulic power unit, and all other required tools and safety equipment. Figures 9 and 10 shows effluent discharge before and after treatment.

Figure 9 Copper containing effluent



Figure 10 Effluent after treatment



Figure 11 shows the treatment system, and Figure 12 a diagram of the process. The system is able to reduce solids content to less than 5 mg/L and copper to less than 1 mg/L.

Figure 11 AHCS Effluent Water Treatment System



Figure 12 AHCS Treatment System Diagram



5.2 SEAWARD MARINE SERVICES MODIFIED SCAMP

Seaward Marine Services, headquartered in Norfolk, Virginia, USA, is the current underwater hull cleaning contractor for the U.S. Navy fleet. They conduct cleanings of U.S. Navy ships on demand using the Scamp three brush diver operated cleaning system used worldwide under license of the Scamp cleaning network. Seaward developed a shroud system for the Scamp to capture cleaning debris and a containment mechanism for their diver held brush system. There was apparently limited testing of the system before it was dismantled due to ongoing work by the U.S. Navy on the AHCS. There was no treatment in this system, just transport of the effluent materials in a hose to a barge for later treatment. There is no other data presently available on this system. In addition, Seaward is developing a "water brush" to replace the bristle brushes. The water brush is designed for the silicone foul release paints, and is claimed to also work on copper ablative paints. Seaward is presently testing a prototype "water brush" single brush diver unit for cleaning silicone paints (Figure 13). It offers the potential for cleaning the silicone paints without damaging the surface. It does not presently have a capture shroud. They also have a U.S. patent on the contained cleaning system, 6070547 of June 2000.

Figure 13 Water Brush Diver Brush Unit from Seaward Marine Services



5.3 CLEANHULL AS CLEANROV SYSTEM

The CleanROV system is an underwater ROV developed by CleanHull AS of Norway (Figure 14). An ROV is remotely controlled from the surface and does not use divers. It navigates by

video and dead reckoning. It uses water jet cleaning, not brushes. They claim to capture the material generated by hull cleaning (<http://www.cleanhull.no/>).

Figure 14 Clean ROV from CleanHull AS, Norway



Their literature states:

"The CleanROV systematically maneuvers around the hull surface using high pressure water, thrusters, cameras, and positioning system. A medium sized tanker or passenger vessel of approximately 20 - 30,000 DWT is cleaned within 5 hours. Our ROV also has the capability to remove waste during the cleaning process, which many ports around the world increasingly require. Cleaning of propellers and rudders is carried out by using certified divers."

The company provided the following information:

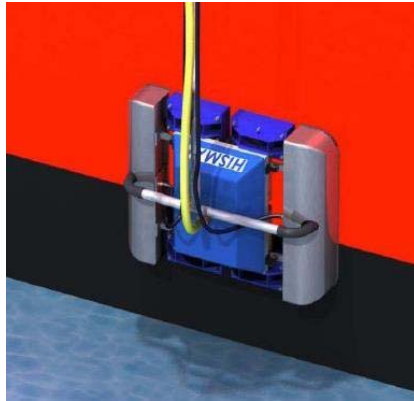
- Our ROV's are fully operational and located in Bergen, Norway, Gothenburg, Sweden and in Algeciras, Spain. We have a fully operational waste return system at the operation in Gothenburg, as this was required by the port authority.
- The high pressure water is crushing the barnacles, so there are smaller particles to assist in transporting the material up the hose. There is a limitation on cleaning very heavy fouling and large barnacles, which can be hard to remove.
- Tests have been conducted on Silicone hull coatings, and approvals given to clean paints from all the major paint brands, such as International, Jotun, Sigma and Hempel.
- We do not remove/filter out the dissolved copper or copper particulates, but our cleaning method is more "gentle" to the SPC antifouling, and we do not remove antifouling in the same way as with brushes, and therefore there is less copper contamination of the sea.

They are conducting further testing in June 2009 to determine if marine fouling in the waste stream can be killed by treatment. They have no specific information on the treatment methods for the waste stream. They do not appear to have a smaller contained unit for cleaning niche areas.

5.4 HISMAR SYSTEM

The HISMAR system (Hull Identification System for Marine Autonomous Robotics) is a proposed system for inspecting and cleaning a ship hull. Figure 15 shows a conceptual rendition of the system.

Figure 15 HISMAR System



It is a joint project of the University of Newcastle Upon Tyne and several commercial and government agencies. The project goals, as stated by the HISMAR web site (<http://hismar.ncl.ac.uk/home.htm>) are:

"This project offers a means to effectively and efficiently undertake hull inspection and maintenance thereby improving the potential safety of the vessel. Cleaning of the hull ensures the vessel maintains the lowest possible resistance which has an extremely large impact on the hydrocarbon fuel consumed. Therefore, ensuring a clean and smooth vessel surface reduces vessel emissions and reduces operating costs."

A UK based maritime technology organisation, Safinah Ltd., was contacted and asked to visit Newcastle University to determine the current state of the HISMAR project. They prepared a short report, which is provided below.

5.4.1 Safinah, Ltd Report on HISMAR Project Status

Safinah has been asked by Marine Technology Consultants of Annapolis, Md. USA to undertake a short review with regard to the status of the "Hull Identification System for Marine Autonomous Robots" (HISMAR) a European Union Framework 6 project (a method of proposing and funding technology development) carried out by a consortium of European partners lead by the School of Marine Science and Technology at Newcastle University. This report sets out the findings of the Safinah review.

HISMAR Overview

Objective

This project aim was to develop a multi-purpose inspection and maintenance platform with an advanced navigation system for marine applications. The device proposed would undertake hull inspection and maintenance while the vessel is afloat.

Outline

The system will be based on a robot that will be able to first of all scan the ships hull and then navigate the hull to carry out cleaning and any other inspection operations.

It is envisaged that the device would be ship borne and so able to carry out underwater hull cleaning on an ongoing basis at successive ports of call.

The device will be able to complete its tasks partially whilst in one port and be re-launched at successive points to complete the task. The platform can be launched whenever the vessel is in port or at anchor. It will also be deployable in a dry-dock situation

Scope of work

The work was broken down into the following eight work packages:

1. Investigation and analysis of technology, equipment and techniques associated with project objectives.
2. Design, manufacture and testing of the integrated navigational system.
3. Design and construction of the hull structure mapping system and intelligent algorithm.
4. Design, construction and testing of the drive and electromagnetic attachment system.
5. Design and construction of the buoyancy outer shell, structural integrity monitoring and cleaning and debris removal 'plug in' modules.
6. Full field testing and analysis of system performance.
7. Project management.
8. Exploitation, dissemination and commercialisation.

The initial stage of the project consisted of a full investigation of end-user requirements including a cost benefit analysis (this was mainly provided by Carnival as a consortium partner).

Safinah made contact with Carnival and they confirmed that they provided some basic details of performance and cost needs. The last contact that Carnival had with the project was 18 months ago and they were not aware of the project completion and had as yet not received any final report.

Progress in work packages

1. Investigation and analysis of technology, equipment and techniques associated with project objectives – was completed with the assistance of ship owners (Cruise and Containership) although it is not clear that any port authorities were approached.
2. Design, manufacture and testing of the integrated navigational system – this seems to have been completed in terms of software development with the appropriate sensing hardware. This work package together with WP3, seem to comprise the real IPR element of the work. It has been tested in the dry and both optical and magnetic systems perform as required. They have not been used in anger, but within June 2009 it is expected to run a trial on a ferry to be docked at Pallion Engineering in Sunderland (UK).
3. Design and construction of the hull structure mapping system and intelligent algorithm – TBC
4. Design, construction and testing of the drive and electromagnetic attachment system – The components used have all been off the shelf items and a working system has been developed to enable the navigational system to be proven. It is however quite some way away from what a final design may be.
5. Design and construction of the buoyancy outer shell, structural integrity monitoring and cleaning and debris removal 'plug in' modules – This has been done conceptually and the elements designed but not made and tested.
6. Full field-testing and analysis of system performance – No really robust field-testing has been carried out of the whole combined system. Some controlled and limited testing of the individual parts has been made.
7. Project management – Done
8. Exploitation, dissemination and commercialisation – Patent protection in place for Navigation system held by University

The Partners

The key partner in this project has been Newcastle University; there is little evidence of huge contribution of other partners. The IPR/Patent rests with Newcastle University. There are no other patents or IPR identified to date.

- Newcastle University
- Shipbuilders and Ship repairers Assoc (Industry Association) – interest in the use of such a system in dry-dock (but technology already exists e.g. Chariot Robotics)
- Graal Tech – Italian robotics company – Spin off from Genoa University very much a research based company
- Techno Veritas – Portuguese company specialising in control systems – Very small start up company
- TEPAC – Patent and IPR consultants
- Polski Register of Shipping – Considering use of such technology for In-water Survey work
- Robosoft – specialising in robotic manipulators – Would sell off the shelf drive systems
- Carnival – Cruise ship operators. Would use such a system if commercially viable.
- Moscow State University – did some software development work
- Thai Navy (the key researcher was employed by the Thai Navy)

Safinah findings

Safinah held two meetings with Dr Rose Norman to try and gauge the status of the project and a telephone conversation with Prof T Roskilly. What follows are the Safinah conclusions.

The conclusion reached is that the project funding has now finished and the work is in abeyance. The University (Prof Roskilly) is seeking additional sources of funding to commercialise the work carried out. However there seems to be a considerable way to go to reach any commercially viable solution.

Safinah does not believe that as yet this is a viable system. It is likely to need considerable development investment by a third party commercial investor. Based on the discussions, Safinah would estimate that any such system is likely to be a minimum of 5 years away from full development and commercial exploitation.

What has been done would seem to be as follows:

A robotic system has been developed that can work on dry ground and can to a limited degree map the surface of a mocked up part of ships hull.

Carnival reported (Mr John Drew) that on the viewing of this robotic device 18 months ago it had not performed its basic tasks as expected. Safinah was left with the impression that Carnival had not seen any significant development, although they clearly had considerable interest in the possibility of a solution.

At present other than a decision made on the basis that the cleaning technology would be based on water jetting and that some parameters for this had been defined (300 bar) no testing was done and no development was undertaken to integrate the water jetting unit into the robot (when asked Safinah was informed that the cost of the water jetting equipment was prohibitive for the project budget).

Status

Safinah understands that currently the University of Newcastle is seeking funding in the form of private equity to develop the system into a commercially viable technology.

Discussions with Dr Rose Norman implied that no funding had yet been identified and certainly did not indicate that any of the existing partners in the consortium had taken up any option for any further development.

The impression Safinah got was that the main development in the project was the control and navigation software. The robotic platform described seemed to be quite crude and aimed really at proof of concept for the navigation of the robot.

No tools were incorporated, and no attempt to make a system that can be immersed and perform in seawater was made, and it is unlikely that will occur within the timescale available.

Thus the system to date has demonstrated that a Robot can be controlled and used to navigate on a dry flat surface (only limited vertical side/curvature work appears to have been carried out to date). It has not been used to prove the cleaning technology/capability, nor has the recycling/recovery system been developed.

The detection system of landmarks as shown on the simulation available on the HISAMR web site indicates that this is likely done by Ultrasound and hence the potential to measure steel thickness is a natural extension of this.

Conclusion

The HISMAR project set out with some bold and much needed ideas and a clear programme of work that was to cover all the required aspects to develop a system for underwater hull cleaning. However it seems not to have achieved much beyond a very limited proof of concept.

Safinah is of the opinion that there is still some considerable research work to be done before the real development could be carried out.

5.5 UMC INTERNATIONAL PLC

UMC International Plc, of Southampton UK, are the developers of the Mini-Pamper multi-brush hull cleaning system which does not presently have contained cleaning (Figure 4). They have also developed a diver operated single brush cleaning unit that has the ability to contain fouling for use in propeller cleaning. It also has a companion filtration unit provided for removing particulates. This unit has potential to be used to clean niche areas. The company claims about 75 percent containment of removed fouling. In addition, they assert that it is feasible to develop a containment system for the Mini-Pamper hull cleaning vehicle if there is commercial interest in such a system. The company provided a brief on the Mini-Pamper and the contained propeller cleaning tool and filtration system shown below.

“UMC has for the last 30 years developed and manufactured its own range of underwater hull cleaning and propeller polishing equipment. This is now available worldwide for use by suitably qualified diving companies.

The present underwater cleaning vehicle, Mini-Pamper, was developed to clean vessels with high curvature and soft coatings enabling it to be used on a large range of vessels from small surface warships and submarines to the largest VLCC's. It incorporates a unique hydraulically operated brush control mechanism which allows the brush pressure to be controlled and automatically lifts the brushes from the surface when the vehicle is stationary, preventing localised coating damage. Recent developments have included special brushes for cleaning lightly fouled silicone based low energy “foul release” coatings which rely on motion through the water for their antifouling properties. The

brush mechanism also reduces biocide laden paint coating diminution by using the lightest brush pressure to achieve successful cleaning.

The next generation of UMC hull cleaning equipment will incorporate waste recovery and processing functions to minimise pollution due to the removal of biocide coatings and to negate migration of species due to hull cleaning. Many countries worldwide already ban in water hull cleaning however, until this is universal, in a commercial world owners and operators will not pay the extra expense of waste processing and disposal.

As a direct requirement of water purity regulations in Holland UMC has already developed a successful waste recovery system for use with UMC's propeller polishing equipment. Primarily created to limit the copper based "fines" from the propeller surface entering the surrounding water, the recovery system also collects any fouling waste emanating from cleaning and polishing operation. The waste processing system is based on the use of disposable filter elements however the next iteration will incorporate process filtration systems to give continuous waste collection without the need for further expensive consumable filter elements. Lessons learnt from this development exercise will be directly transferable to the waste recovery on a full hull clean.

To further the cause of waste recovery a realistic target for water purity needs to be defined. At present water authorities require water returned to the water course to be of near drinking water purity. This requirement ignores the fact there may already be pollutants locally in the water which are nothing to do with the hull / propeller cleaning operation under review. Hull cleaning companies cannot be expected to purify water polluted by others. Figure 16 shows the waste recovery filter developed for propeller cleaning.

Figure 16 Waste Recovery Filter for UMC Propeller Cleaning Head



6. Practical considerations for utilising contained hull cleaning

The effective implementation of underwater hull cleaning to remove NIS from ship hulls entering New Zealand and other international ports will require sufficient numbers of hull inspection and cleaning systems so as to service the major ports in the country. There are at least 16 ports where ships arrive from overseas voyages. Data provided by MAF indicate that there are approximately 3000 to 5000 major vessels that call at New Zealand annually. There would have to be an inspection system established to determine if these ships are carrying marine NIS and require cleaning. Criteria would have to be established to make that determination. An approximate average for inspections could be as frequent as about 30 inspections a day, every day of the year. This is a significant work load, but it could be handled by teams of trained individuals. I would recommend the use of small ROVs (Figure 17) for this task, supplemented by divers if there was an issue that required hands-on evaluation.

Figure 17 ROV for Ship Hull Inspection (U.S. Navy Photograph)



Small ROV systems are quite capable of doing rapid inspections of selected areas of large ships to determine the type and distribution of fouling present on their hulls (Bohlander 1999). These systems range in cost from US\$40K to US\$250K depending on size and complexity. Underwater video can be taken and reviewed by marine experts to identify the fouling community on the ship hulls. The largest ports, such as Auckland and Tauranga would require the most inspection systems. Smaller ports could possibly share systems.

The number of underwater hull cleaning systems capable of contained cleaning that would be required to protect international ports is difficult to estimate. These contained cleaning units are not available at this time. The number of units needed would be dictated by the number of arriving hulls that required cleaning. It is also difficult to estimate that number. Should international regulations regarding contained underwater hull cleaning be initiated, essentially all current hull cleaning systems would have to be converted to capture systems. This would then require all ships cleanings to be contained, and would serve to assure the destination country that the ship was not carrying NIS. It should also be noted that cleaning of cuprous oxide based AF paints will generate a discharge of copper as well as marine fouling. Even if the capture process is efficient, the removal of particulate and dissolved copper from the

captured waste water stream will have to be accomplished. The U.S. Navy AHCS does have this capability.

There are no accurate costs presently available for contained underwater hull cleaning. This service would most likely be contracted out to underwater hull cleaning vendors, and not involve outright purchase of systems. The costs charged to the customers would likely include amortizing the capital costs of the captured hull cleaning system, operational costs, and also costs for processing potentially large waste water streams. As an example, U.S. Navy ship non-contained cleanings costs range from US\$15,000 for a small frigate to US\$75,000 and up for an aircraft carrier. One could assume that these costs will rise for contained cleaning.

Information needs to be gathered to determine the fouling condition of ships currently arriving in New Zealand waters. There is currently a program that has examined 10 percent of the ships entering the country to collect this data. The report from this effort is expected to be published in the near future. It is also apparent that there are no fully capable contained underwater hull cleaning systems yet commercially available to that can handle the projected work load. The commercial underwater marine technology sector requires time to respond with investment in this process if it determines that there is a customer base for this service.

7. Summary and Conclusions

The challenges involved in developing a contained underwater hull cleaning system for large ship are significant. There are many different hull configurations, fouling conditions, and hull antifouling paints. The paints may be the ablative or copolymer paints containing cuprous oxide and organic pesticide co-biocides as the toxicant or might be the non-toxic foul release paints based on silicone. The fouling condition is likely to be different for the two classes of paints. The cleaning process using brushes or water jets will disperse the particulate matter generated during cleaning, which is both biological material and paint residue, into the water column. These particles have a large range of sizes and are difficult to capture. In addition, marine fouling is likely to be present in niche areas of the hull. These areas are difficult to access, and may require custom cleaning tools, along with specially designed, adaptable containment and capture systems to effectively prevent fouling debris from escaping. This will require collaborative work to determine sizes and shapes of portable containment systems.

This investigation revealed four underwater cleaning systems that were designed to contain and capture cleaning effluent and transfer this waste water stream to the surface for treatment (Table 2). However, only two of those systems appear to be operational, the U.S. Navy's AHCS and the CleanHull AS CleanROV systems. Only one of those systems, the AHCS, includes a waste water treatment system along with the capability to process larger calcareous fouling. The other two systems, the Seaward Marine Services modified Scamp, and the University of Newcastle Upon Tyne HISMAR, are either not currently in service (Seaward) or are a conceptual design (HISMAR) that has not been constructed. The Seaward Marine system could probably be reconstituted in the near term with a funding investment from interested parties. The HISMAR system is likely a considerable time away from a prototype as it still awaits funding to develop many aspects of the system. The AHCS system is the most technically advanced system with the most data on its operation. Discussions should be initiated with appropriate U.S. Navy personnel at NAVSEA to determine the feasibility of evaluating this system for possible use by New Zealand and other countries interested in captured hull cleaning. However, it should be noted that this unit is a prototype, and significant capital investment, as well as time, would be required to produce multiple systems. Commercialisation of this system can be accomplished by Oceaneering, Inc, who designed the system for the Navy, or by a technology company with the appropriate skills. The UMC single brush unit for contained propeller cleaning, should be considered for cleaning niche areas.

Table 2. Captured Underwater Cleaning Systems

SYSTEM	COST ^{a,b}	CLEANING METHOD	AVAILABILITY ^b
AHCS	>1M \$US	Brush	Limited
Seaward Mod Scamp	Unknown	Brush	No
CleanHull ROV	Unknown	Water Jet	Selected Locations
HST Hot Water	Unknown	Hot Water	Australia Locations
HISMAR	Unknown	Unknown	No
UMC	Unknown	Brush (niche areas)	Yes

Notes:

a: Cost figures for most systems are proprietary

b: Most companies do not sell systems, but own or lease and operate them with trained personnel

It is recommended that a statistically-based underwater hull inspection process be initiated. This would allow the collection of data on the actual hull condition of ships entering waters of

interested countries. This data should provide enough information to help decide if hull cleaning to deter NIS is feasible. Regulatory guidance should also be sought through the IMO MEPC to determine the overall feasibility of requiring contained underwater hull cleaning to limit the amount of marine NIS and copper discharged into the harbor waters.

Should there be worldwide consensus that contained underwater hull cleaning would provide a benefit in managing marine NIS, there should be an effort made to communicate this policy to the underwater technology marine industry. The success of the USN AHCS shows that contained cleaning is feasible. While there are few systems currently available for this task, the marine technology community would likely respond to the creation of a change in the market for their services. This will require communicating this need worldwide to this community. This effort could include attendance by a delegation representing this developing need, at major underwater technology conferences such as Underwater Intervention, Oceans, Ocean Business, the World Maritime Technology Conference, and others. Professional marine technology societies such as Society of Naval Architects and Marine Engineers (SNAME), American Society of Marine Engineers (ASNE), The Royal Institute of Naval Architects, and others should be contacted to communicate to their members the opportunity to participate in the development of contained underwater hull cleaning systems.

8. Recommendations

- Establish liaison with the U.S. Navy NAVSEA OOC5 to track progress of the AHCS and initiate discussions with their contractor for the feasibility and costs of evaluating the unit in for use worldwide based on action by the IMO.
- Evaluate the UMC contained diver held single brush unit for niche area cleaning and effluent processing.
- Monitor the CleanROV, UMC, Seaward Marine Services and HISMAR efforts to develop and test a contained cleaning unit to determine progress and suitability for use both in New Zealand and worldwide to reduce marine NIS.
- Participate in the IMO MEPC regulatory process to determine a consensus on the environmental need and economic feasibility and effect on world shipping of a contained underwater hull cleaning requirement.
- Initiate a vigorous effort to communicate the need for contained underwater hull cleaning systems to the world community of underwater technology corporations by participating in conferences, seminars and professions meetings and by conducting outreach to marine technology developers. These systems will not be developed unless a clear market for these services is apparent to the corporations that supply underwater maintenance services.

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Appendix 1. Advanced Hull Cleaning System



Advanced Hull Cleaning System

The Advance Hull Cleaning System (AHCS) developed by Naval Sea Systems Command (NAVSEA) is a mobile system capable of rapid deployment to ships berthed pier side to perform underwater hull cleaning. This new system provides the traditional benefits of hull cleaning along with the means of complying with existing and anticipated environmental regulations governing the cleaning of Navy ships. The direct shipboard benefits include; enhanced operational readiness, reduced fuel consumption, extended periods between dry-dock, extended underwater hull coating service life, reduced hull acoustic signatures. The AHCS is contained on two 48' trailers; one for the mobile support unit and cleaning vehicle, and one for the effluent wastewater management unit.



Advanced Hull Cleaning Vehicle (AHCV)

The AHCV, model MK-1C, is one critical component of the integrated AHCS. This diver operated vehicle removes the marine growth from the hull and reduces heavy metals and marine fouling discharges into the environment by capturing the debris and transporting the effluent to the pier side WMU prior to it's discharge to the sewer.

Mobile Support Unit Features		Advanced Hull Cleaning Vehicle Features	
Dimensions (L x W x H)	48' x 8' 6" x 13' 2"	Dimensions	122" L x 44" H x 78" W
Trailer Weight (EST)	56,000 LBS	Weight	2600 LBS
MSU Trailer Type	Double Drop	Brushes	19" NAVSEA OOC Type E1, E2, E3, or E4
Generator	175 KW	Cleaning Swath	57" maximum
Fuel Tank	100 gallons diesel (24-hour duration)	Cleaning Speed	Variable, 1 FT/Sec maximum
Crane HPU	30 HP, separate crane/reel manifolds	Cleaning Deck	Retractable, Flexible seal, hinged brushes, gimballed mount with 4-Bar linkage
Diver Hot Water Heater	3-Diver type. 600' ½" hose	Particle Reduction	Hydraulic Crusher, .33" nominal particle size, diver operated control
Control Van (L x W x H)	15' x 8' 4" x 8'	Effluent Pump (Electric)	30 HP, 240 GPM @ 170 Total Dynamic Head (TDH) in Feet.
Dive Locker (L x W x H)	10' x 8' 4" x 7' 2", w/ machinery and diver spaces	Particle Separation	Krebs Hydrocyclone, Recirculating (EST) 150 GPM overflow back to cleaning deck
Umbilical Hose Reel-Hydraulic	600' of 6" OD umbilical	Effluent Under Flow rate	55 to 70 GPM returned to pier through 2" ID x 600' long hose plus 100' long minimum of 2" ID discharge hose to Filtration Trailer
Articulating Crane (National N160/46)	9 Ton MAX, 2700 LBS @ 46 FT	MAX Vertical Head	25 FT MAX Pier Height plus an additional 8 FT Vertical Head routed to Filtration Trailer
Power Block-Hydraulic	19" ID Sheave	Drive	3-wheel drive, 2-fixed/1-steering with 180 degree rotation, variable speed-.5 to 1 FT/Sec
2 Handheld Cleaner HPU/Reel	7.5 HP, each hose ½" ID x 300' Long	Hydraulics	30 HP, 3-circuit closed system with cooler
		Controls	Diver actuated drive controls with Topside HMI Display, Video Display, Hardwired Motor Controls, PLC interfaces, and Ground Fault Monitoring

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Advanced Hull Cleaning System

Effluent Wastewater Management Unit (WMU)

The effluent WMU is the second component of the integrated AHCS to process the AHCV wastewater via primary settling, chemical precipitation, ACTIFLO® sand ballasted clarification, and sludge dewatering. The trailer is equipped with a programmable logic controller, human machine interface, diesel powered generator, air compressor, hydraulic power unit, and all other required tools and safety equipment.



Underwater Hull Fouling

System Influent

System Effluent

Dewatered Solids



WMU Exterior
Features and Process Performance

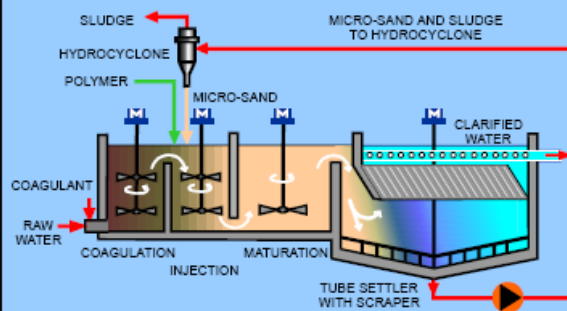
Process Tanks

WMU Interior

Dimensions (LxWxH)	48' x 8'6" x 13'5"	Coagulant Storage/Use ⁴	160 Gal 10 Gal/Day
Est. Weight (lbs)	54,000 dry 94,000 wet	Polymer Storage/Use ⁴	180 Gal 1 lb/day
Generator	100 kW	Sand Use	300 lb/cleaning
HPU	7.5 HP	Actiflo® Module	1,600 Gal
Compressor	20 Gal at 3.9 CFM	Primary Clarifier	660 Gal
Water Heater	10 Gal	Sludge Thickener	528 Gal
Sea Water Hose Reel	1/2 HP, 100', 2"	TSS (mg/L) ^{1,5}	885 input <5 output
Discharge Hose Reel	1/2 HP, 100', 2"	Copper (mg/L) ¹	31 input <1 output
Overflow Hose Reel	1/2 HP, 50', 3"	Zinc (mg/L) ¹	22 input <1 output
Service Water Hose	50 gpm min, 100', 2"	Waste: Sludge Dry Solids ²	3 bbbls/day 250 lbs/day
Caustic Storage/Use ⁴	160 Gal 16 Gal/Day	Discharge (gpm)	66 nom 90 max

¹ Input levels represent ave values from field tests. Output levels represent most stringent limits from field survey ² Est based on ave influent TSS. ³ Effluent (output) particle size <0.5 microns. ⁴ Based on 20% NaOH, 43% FeCl₃, 8 hr day at nominal flow rate. ⁵ Based on ave field test values.

Core Technology: Actiflo®



The Actiflo® process uses micro-sand to enhance settling properties, that allows system to be between 5 and 20 times smaller than conventional clarification systems of similar capacity.

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