BIOLOGY AND H.M. SHIPS—II

MARINE FOULING

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The importance of keeping the underwater surface of a ship's hull as smooth as possible to enable it to reach a performance approaching its design capability, is still not universally recognized by those most closely associated with the operation of ships.

The present method of obtaining protection, from the point of view of corrosion and fouling, is by painting the hull with a suitable composition. This operation is often the most hurried part of the in-dock treatment. Care in the application of these paints would pay handsome dividends. It is a case of out-of-sight out-of-mind because there are no immediately obvious indications of the benefits to be derived.

There are, however, a few examples which emphasize the need in a dramatic way. Admiral Rodney's victory over the Spanish in the West Indies in 1780 was, apart from tactical skill, attributed to the fact that the outer bottoms of his ships were clean because of their being coppered. Indeed, in the last war, the loss of the Pocket Battle Ship, *Graf Spee*, was attributed by the German High Command to the fact that she was foul through being too long out of dock with a consequent loss of speed and manoeuvrability. More recently, in 1968, the R.M.S. *Queen Mary* was idle for eight weeks in Southampton Water due to a seamen's strike. The ship was cleaned by divers before sailing but took an extra day on her journey across the Atlantic. Part of the trouble turned out to be a cracked propeller. This defect was rectified and the opportunity taken to clean and paint the outer bottom. Significantly, on the return journey, she equalled the time of her record making blue riband crossing which had been set up thirty years earlier.

It is very difficult to obtain precise figures for the cost of fouling, but some attempts have been made to obtain reasonably reliable estimates. Among the more recent[1] it is stated that even moderate fouling on a tanker can increase the fuel consumption required to maintain speed by 30 per cent. Another estimate[2] states that during the life time of a frigate or destroyer about half the fuel consumed is used in overcoming the drag of the water on the hull. In addition, it records that of the R.N. fuel bill of £20m per annum, £3·8m is spent on overcoming the effects of roughness and fouling.

The recent economic crisis does appear to have produced a greater awareness of the fouling problem. The penalties involved are due to the increase in skin frictional resistance which reduces the top speed attainable by several knots and produces a marked increase in fuel consumption when maintaining the normal cruising speed. In addition, there are the costs of taking remedial action and loss of earnings during that period.

The species which constitute fouling are those sedentary organisms which occur in nature on substrates that afford a reasonably firm base on which they can settle. Some of these species, or at least their near relatives, can be seen on the sea shore and others may be seen diving in coastal waters. However, not all the species occurring in these habitats are found in ship fouling. Indeed, the list is short in comparison to the number available. The phenomenon is generally regarded as being restricted to harbours and coastal waters. There is an exception to this rule which was well known to the Captains of the old Clipper Ships who had a dread of being becalmed in the open ocean, not only because this cost them time on their journey but also because they were almost certainly going to collect stalked barnacles on the outer bottom. From experience they knew that these would seriously affect the speed of the remainder of their journey. The problem has now re-appeared on tankers which have stopped to carry out cleaning operations at sea.[3]

When a non-toxic surface is immersed in the sea, it quickly absorbs organic compounds and within hours there will be a flourishing growth of bacteria.[4] This will be followed by the microscopic algae (the diatoms) and those animals, some of which show plant-like characteristics, the Protozoans. These are the organisms which are the members of the so called slimes. Subsequent colonization is by the macroscopic species of algae and animals, which are the ones commonly seen on ships' hulls. There is a good deal of speculation about the sequential nature of the build-up being due to the conditioning of the surface before settlement can occur, or, conversely, it may prevent others from settling. Whilst there is evidence to support these views, it has been difficult to establish such relationships with any degree of certainty. In practice, it is observed that the most important fouling species appear to need little conditioning, if any, of the surface before being able to colonize it.

Fouling of ships occurs because there is an overriding necessity for the sedentary organisms in the sea, whether they be plant or animal, to find a suitable firm substrate on which to settle in order to complete their life history. There are, however, certain differences between them. The most obvious is that the algae settle profusely in the more well lit areas close to the sea/air interface. Although on the whole the competition is not mutually exclusive, animal species tend to settle in greater numbers further down on the hull. There is also an important difference in the conditions under which they can settle. A water speed of 2 knots over the surface will effectively prevent the settlement of all animal species. This is not true for the algae whose spores can attach even when the vessel is moving at apparently high speeds.[5] The explanation appears to be that the spores of the algae are small enough to enter that part of the hydrodynamic boundary layer surrounding the hull known as the laminar sub-layer immediately adjacent to the surface. They are thereby protected from the shear forces which would otherwise tend to dislodge them. The animal larvae, on the other hand, are by comparison large and can only obtain protection when the laminar sub-layer is relatively thick, which occurs only at low speeds.

One of the incidental consequences of ship fouling is the spread of species to other parts of the world where they have not previously been established. Perhaps one of the more spectacular was the barnacle *Elminus modestus* which was well known in the temperate regions of the Southern Hemisphere but not in the Northern. In 1944, one specimen was found on a non-toxic panel exposed in Chichester Harbour. The conditions obviously suited the newcomer for it is now found all round the coast of the British Isles and along the European coast from Spain to Denmark. The most probable explanation is that the species was introduced on the hull of a war ship making a fast passage to the United Kingdom and was thus able to survive the journey through the tropics. The sea-squirt *Styela clava* was almost certainly brought back to our waters on the bottom of a tank landing craft returning from the Korean War and was first found in Plymouth Sound in 1953. These two examples are interesting because in the case of the barnacle a fast ship was the means of introduction whilst the sea-squirt was brought back by a slow moving vessel. If the position had been reversed, it is extremely unlikely that either species would have reached these shores. Slow passage through the tropics would have been too much for the barnacle and with a fast moving ship the sea-squirt would have been torn away long before it reached these shores.

FIG. 1—PHOTOGRAPH OF LIVING SPECIMENS OF STALKED BARNACLES REMOVED FROM THE SAILING YACHT 'BRITISH STEEL'

The most important fouling species are those with hard shells such as the calcareous tubeworms, oysters, and barnacles. The latter are probably the most ubiquitous and are the dominant species in fouling in many parts of the world. However, in areas such as the Mediterranean the calcareous tube-worms dominate and the barnacles are more minor members of the fouling community. Mussels are of little consequence in the fouling of the outer bottom of active ships being quickly swept away, if they have settled, when the ship is moving at speed. They are, however, a problem when they settle in ships' sea water systems. Although they are usually the most troublesome, other organisms such as barnacles and hydroids are also frequent colonizers. The latter are often found in great profusion in the end-boxes of heat-exchange elements and the former frequently make a significant contribution to reducing the bore of the pipes associated with these systems. Another problem which arises, due to individual mussels, is that of inducing impingement attack and hence perforation of heat exchanger tubes. Intake screens may be blocked by dense mats of free floating seaweed which get drawn over the inlet and form a very efficient filter which allows only a very much reduced quantity of water to flow through it. On odd occasions the soft bodied tunicates (sea-squirts) have been reported to have produced the same effect.

It was not until the last two decades that very much attention was paid to the algal fouling because it was not thought to contribute significantly to the drag. There was even a feeling among some people that as they contained mucopolysaccharides they would reduce the effect. This has been shown to be a nonsense since the order of increase in skin frictional resistance is comparable to that caused by animal fouling of a similar intensity. It has also been demonstrated that the presence of the slime forming organisms contributes markedly to skin frictional resistance.

The way in which fouling organisms reproduce differs from species to species and from the plants to the animals, but this is one of the most important factors in their survival. The common element is that all the reproductive elements, whether it be spores of the algae or the larvae of the animal species, are shed into the sea and are at the mercy of the currents for some time. This period may be very short or of several weeks duration. Probably the most common species of algae to be found in ship fouling are those of *Enteromorpha* which are usually responsible for the 'grass' at the water line. These species reproduce by both sexual and asexual means. In the former, motile gametes are formed which fuse together producing a zygote which settles and grows into a new plant. Asexual reproduction is achieved by division of the contents of the cells of the thallus into 16–32 zoospores which are shed and settle without fusion to produce new

FIG. 2—CLIMAX COMMUNITY OF FOULING SPECIES ON A NON-TOXIC PANEL EXPOSED IN TEMPERATE WATERS DOMINATED BY TUNICATES (SEA SQUIRTS)

plants. There is some evidence to show that in these species the gametes do not always fuse before settling and new plants are produced parthenogenetically. The period spent in the plankton can be extremely short in these species. The barnacles, however, reproduce by a sexual process but self-fertilization can occur, at least in some species. After fertilization, the eggs develop into larvae known as first stage nauplii which are released into the plankton; these then go through successive moults becoming increasingly complex through the naupliar stages I–VI and finally develop into a cypris stage which is the one that settles on any surface that happens to be available. The total length of time spent in the plankton can vary from one to several weeks which allows for a greater chance of dispersal.

Despite the fact that there is an over-riding necessity for barnacle larvae to find new settling sites and although they can 'swim' they are largely at the mercy of the currents and will find a new surface mainly by chance. The process, however, is not an automatic affair.

The cypris will explore the surface 'walking' on its antennae and will often detach and alight on another part several times before final attachment. They will also, when given the choice, settle in greater numbers on dark as opposed to light surfaces. Removal of the choice will lead to attachment to whatever surface is available. They also preferentially settle alongside protruberances such as a paint brush hair trapped in the painted surface, aligning themselves neatly on either side. They also occur in grooves in the surface. In the motile larvae such as a cypris, it is not difficult to see how this could be achieved, but the same phenomenon is also to be found in the settlement of algal spores.

The major problem is to prevent the attachment and development of fouling species, a process in which copper has been prominent, first as copper sheathing where the prime purpose was to prevent the ingress of 'ship-worm' and to a lesser extent 'gribble' into the ships' timbers. However, it was discovered that the copper would also protect the outer bottom against sedentary organisms. Later when paints were developed, cuprous oxide was found to be a very effective poison and its use has continued until the present day. Even with modern paints which utilize other toxins (e.g. TBTO), copper is often included in the formulation. The main problem with the copper-only paints is that they lose their effectiveness after they are dried out for any prolonged period. Although it is difficult to establish a precise time limit, 7 to 10 days is usually sufficient to produce this effect. The phenomenon has considerable importance for ships with a large change of draught between the laden and unladen condition.

The only practical means of protecting a hull, at the present time, is by the use of a paint which provides a controlled release of an effective poison. Alternatives to the conventional paints, such as Self-Polishing Co-Polymer, have been devised to give greater controlled release but they are not effective on ships which are stationary for a considerable amount of their operational time, as is the case with naval vessels in peace time.

Fouling/Antifouling Research

The requirement to be met in the fouling/antifouling field is the development of longer lasting antifouling paints. Two approaches have been made, the first to attempt to increase the life of conventional paints by increasing the thickness of the applied coating and secondly to procure, either by intra and extra mural research or through commercial sources, new poisons to replace the presently used copper I oxide (cuprous oxide). The drawback of using thicker coats of cuprous oxide paints is that they are subject to inactivation by 'drying-out'. Furthermore, in black paints the masking of the copper I oxide by carbon black gives rise to a markedly inferior paint with less than half the life. Another approach to the problem is to find a new poison with a longer lasting action. This is no easy task. The compound must be capable of controlling all fouling organisms for periods of four to five years, it must have low solubility, be non-toxic or relatively so to man, be compatible with film forming media, and present no environmental hazard.

All candidate new poisons must be screened to determine their suitability for inclusion in paint media. This is carried out first by a simple raft test where the compound is held behind a porous membrane and, if it gives a promising performance, it is subjected to laboratory tests. These are carried out using barnacle larvae and algal spores. If the good performance on the raft is confirmed then the compound will be incorporated in experimental paint media and tested on raft exposure. If the paints are promising then further development of the media will be undertaken to get the longest possible lasting effect of the poison.

A sobering thought is that it can take anything from ten to fifteen years to get a new composition verified and into service. It is with this problem in mind that attempts have been made to develop accelerated tests for these paints.

In addition we have to seek alternative practical methods for achieving antifouling but must admit that up to the present no such system has yet been developed which would be suitable for use on ships.

Conclusions

The need in the field of fouling/antifouling research is for the development of a new poison capable of providing an effective long-life antifouling paint.

Alternative methods of achieving antifouling should be investigated and because of the long time required to develop new antifouling paints, particular attention should be paid to the development of accelerated tests.

References:

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