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Director
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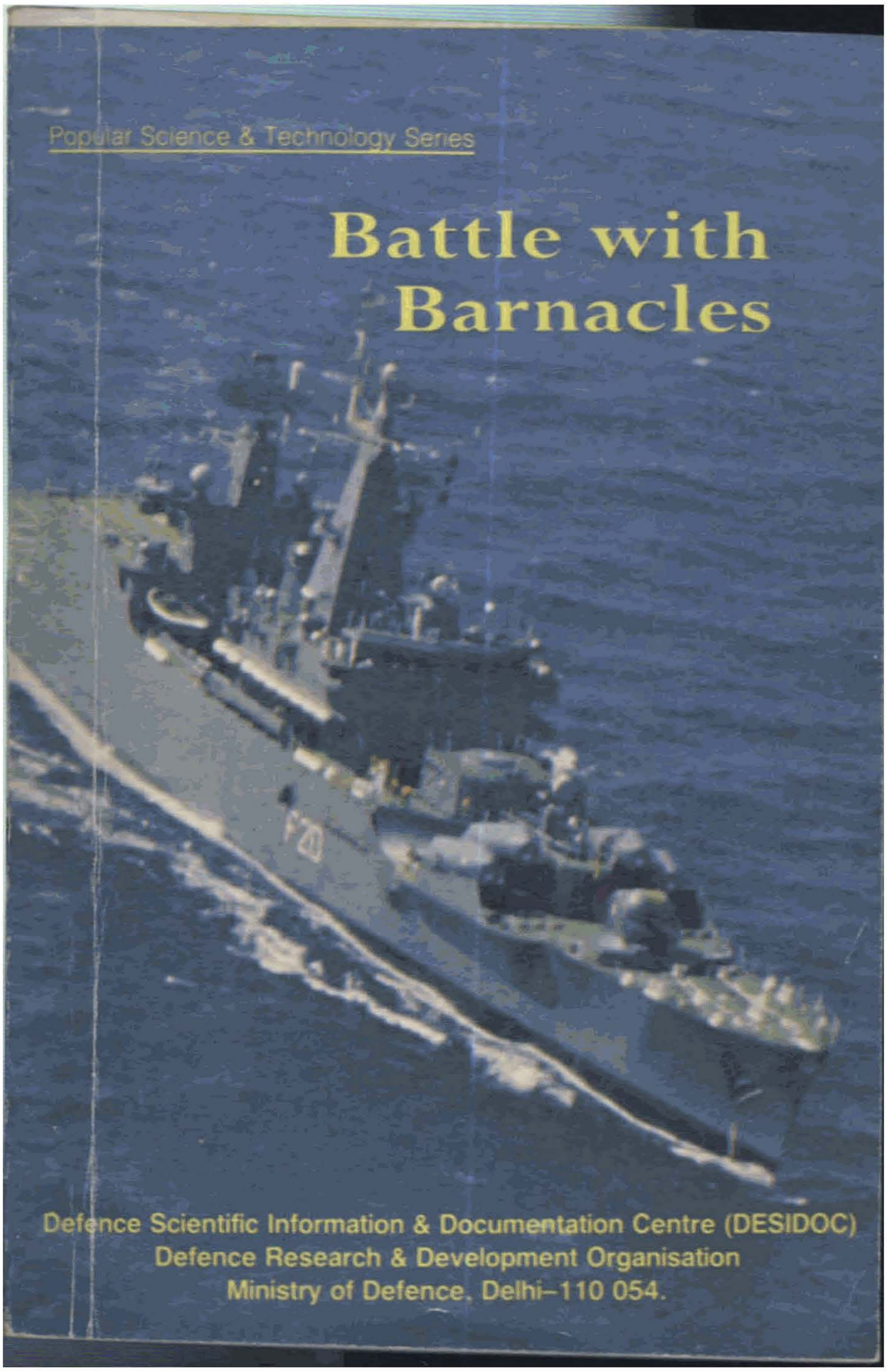
Popular Science & Technology Series

Battle with Barnacles



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Cover Design	S.K. Saxena

Battle with Barnacles

S.S. Ganti
Scientist
Naval Chemical & Metallurgical Laboratory
Bombay

Defence Scientific Information & Documentation Centre
(DESIDOC)
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Preface

Communicating the results of R&D and their various applications, to the vast population not engaged directly in the field of S&T is of national importance. Presenting such developments in a popular style would help in creating. a general awareness among the readers and also in inculcating the spirit of scientific temper in them. The PST series brought out by DESIDOC present overviews on topics of Defence interest in a non-technical language. The present one concerns ships.

The ships sailing on the seas have to fight the twin enemies of fouling and corrosion. In this issue, "Battle with Barnacles", Dr. Ganti has described the various marine organisms and how they attack ships and other man-made structures in the sea. The various steps taken in protecting ships from this fearsome foe culminating in the development of chemical paints have been outlined. Similarly, corrosion attacks all metallic objects indiscriminately. The developments in corrosion prevention techniques have been described comprehensively. The presentation is all along in a popular, non-technical language and is supported by several illustrations. The work being done in this field by the Naval Chemical and Metallurgical Laboratory (NCML) has also been touched upon appropriately.

It is hoped that this publication would stimulate interest and curiosity of the readers, enlighten them on the subject and thus achieve the aim of generating a sense of awareness and enthusiasm for topics of Defence Science.

(R. Krishnan)

Director, NCML

Bombay
May, 1987

Vol.19 No. 1 June 1987

Contents

Acknowledgement

The author wishes to express his sincere thanks to the Director of his laboratory, Dr. R. Krishnan for suggesting to write this small booklet and his constant guidance all through the subsequent stages of its progress. He is thankful to Dr. P.C. Deb who critically read the manuscript and suggested improvements wherever needed. At every stage his colleagues helped him during this task for which he wishes to thank them all collectively. Finally, he is thankful to Dr. A.A. Karande for agreeing to the inclusion of his small poetic tribute to the barnacle.

Fight against Fouling

Barnacle Song

Tin-tina-bulam, mega-tin-tina-bulam,
that is what I am, a twelve legged phylum.

On a claw of crab or back of a turtle,
whichever I choose, I swim and settle.

Stick I to a teflon-smooth, grow in a surf zone,
make no mistake, when it comes to a rolling stone.

Shoulder-to-shoulder, we cluster on boulder,
Alas, on a ship-hull, that menacing intruder.

I am a communis, a clan of gregarious Balanus,
Well connected to Lady Ibla, and prosporous Chthamalus.

There out, over the land, they give me foul name,
I cannot care less, it is all in the game.

I am firm and steadfast, the cement is the secret
Let me not talk about it, lest do I regret.

Dr. A.A. KARANDE,
Biologist,
N.C.M.L.
Bombay

Fig. 1 : A battle-ship sailing majestically in the sea

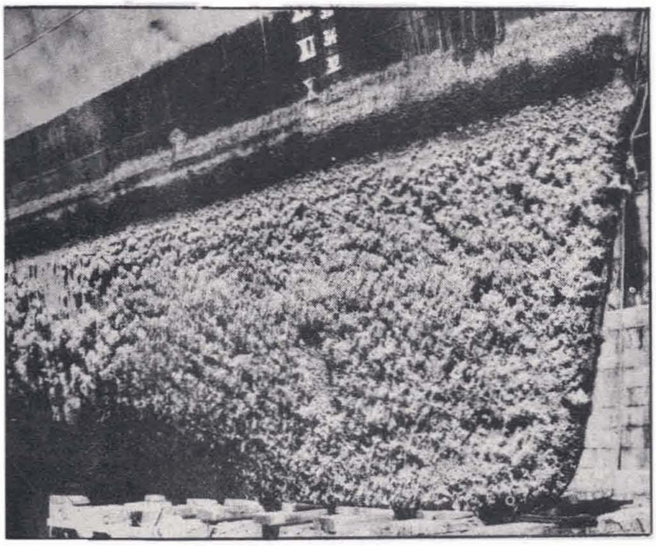


Fig. 2 : The ship battle-scarred with barnacle fouling

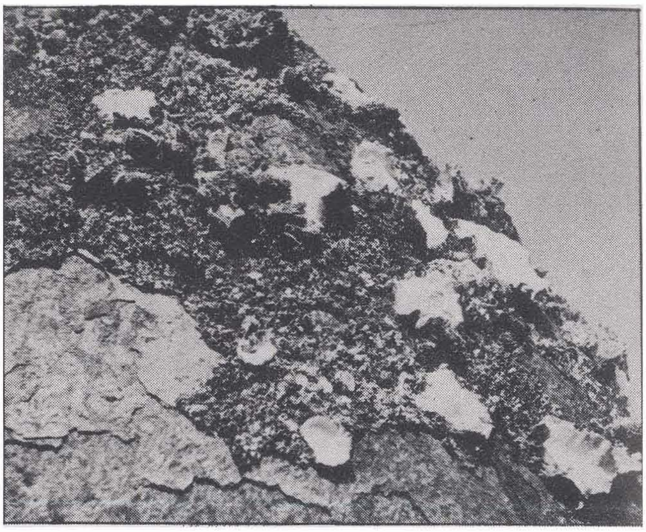


Fig. 3 : A portion of marker buoy showing extensive fouling

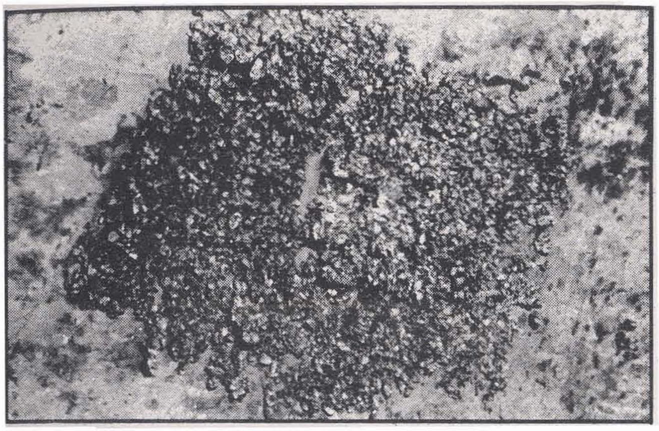


Fig. 4 : Seawater inlet blocked by mussel fouling

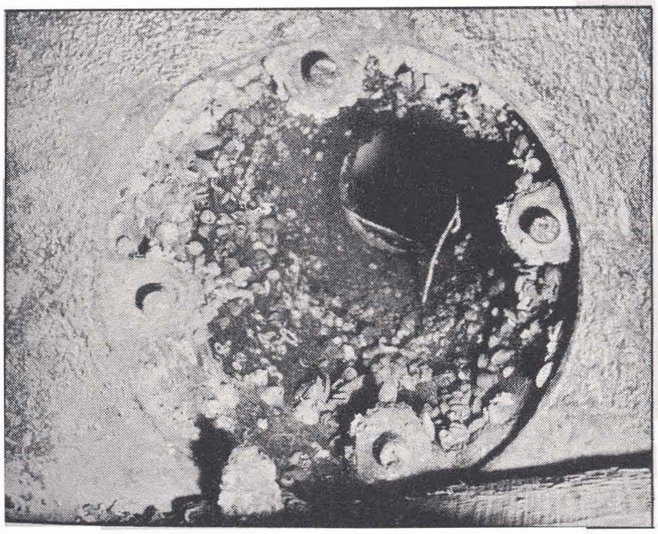


Fig. 5 : Interior of same inlet showing barnacles

Part I : Fight Against Fouling

1. The Silent Battle

1.1 THE ENEMY IS IDENTIFIED

Since time immemorial a battle has been raging between the creatures of the seas and man. It began the day man launched his first boat on the sea. The ceaseless war spanning several centuries is yet to prove decisive.

There are many types of marine animals and plants. They settle on rocks, boulders as well as man-made structures. The phenomenon of the organisms attaching themselves to the undersides of ships is called fouling and thus their community can be collectively christened the 'fouling community'.

A ship is not regarded as battle-worthy if its bottom is fouled. The fearsome foe of the fighting armada, the fouling organisms, are wily. They attack in many ways. By clever maneuvering and incisive jabbing, they penetrate the thick armour of the armada and impair the activity of even the strongest of these naval vessels.

The leader of this fouling community is the boneless barnacle. Fouling of ship is not serious unless the barnacles form a part of it. Thus while all types of foulings are to be combated the battle is mainly between the barnacle, in particular, and mankind.

1.2 THE ENEMY'S CRIPPLING TACTICS

A naval architect spends his lifetime on the drawing a boards in designing every line and contour of the battleship. The fabricator translates it into a beautiful, streamlined ship calculated to give maximum speed. But their efforts are in vain as the most simple and harmless looking bacteria and diatom present in the sea, form a slimy film on the underside of the ship within a day of its launching. The percentage increase in resistance offered by such a slimy surface is six times the stipulated value. When barnacles and other fouling organisms settle on the surface, the resistance increase is is manifold.

The first and foremost effect of the frictional cc resistance due to fouling is reduction in speed. A reduction in speed of the order of 1.5-2.0 knots has been observed in different classes of warships. However, the effect on fuel consumption is not directly proportional to the extent of fouling. In a small sized destroyer, there is a 50% increase in fuel consumption to maintain a nominal speed of ten knots. This figure is valid only for temperate waters. The rate of increase in frictional resistance is much higher in tropic waters where fouling is extremely heavy.

The propulsive force of a ship determines the e speed of the ship. In practice, this force is estimated from the shaft horsepower. The effective horsepower (EHP) of a ship is generally less than 75% of the shaft horsepower. The reduction is primarily due to turbulence at the propellers.

The power of the ship is decreased further with settlement of fouling. The experiments conducted on a destroyer in the United States showed that, eight e months after undocking, the ship required virtually double the initial shaft power to achieve a speed of fourteen knots. The reason was that the foul power d had overpowered the shaft power!

The fouling of the propellers adds to the woes of the architect. A British ship failed to develop the anticipated speed even on a trial run because of the settlement of fouling organisms. It has been estimated that about two-third of the increased fuel consumption is accounted for by the effect of fouling on propellers alone. An increase of as much as 115% in fuel al consumption has been observed in a ship just seven A months after undocking.

1.3 UNDERMINING THE MINES

Territorial waters of a country are protected from enemy ships by placing explosive mines near the coast. These mines, which are immobile, are moored at depths effective to blow an enemy ship without being detected. The depth at which a mine is to be placed is predetermined and is crucial for it to be effective. The fouling of mines is very rapid, and, in a short time, the mine is camouflaged to the greatest relief of mine laying ships. But this pleasure becomes shortlived with exposure for longer periods. The fouling organisms, which settle in a continuous process, increase the weight of the mine and displace it from the depth at which it was placed with catastrophic results. The mine now becomes a beautiful specimen for fouling studies, so that the fouling is fine but not the mine.

1.4 THE ENEMY ATTACKS TRAFFIC SIGNALS

A coastline is generally demarcated with navigational buoys. These buoys are moored permanently and have the important function of protecting the ships from destruction by acting as traffic signals, and warning the ships from straying too close to the coast which is shallow.

Thus, the buoys have to remain floating till they are replaced by new ones. Buoys are placed at different depths. Unfortunately, these buoys, like the mines, are not immune from fouling and get coated with varying amounts of fouling, depending on their position. As. a result, their weight increases. Hence these buoys have to have sufficient reserve buoyancy to counteract this weight increase due to fouling but these preventive measures are not easy to achieve.

1.5 THE ENEMY AND THE ECHO

Special equipment are deployed to record the sound produced under water. The commercial vehicles are commonly equipped with sonic sounding devices while naval vessels are equipped with sonar sounding domes. These devices are also subjected to fouling.

Fouling on the sound equipment is totally undesirable since it generates unwanted sounds which are also picked up by the receiving mechanism. The opening and closing of the operculum of barnacles and the shells of oysters or mussels produce so much noise that they camouflage the sounds made by the enemy vessels and help them to escape detection.

Sonars operate on the principle of production and reception of ultrasonic waves which after transmission are reflected from the surface of another underwater object. The calcareous and siliceous shells of the fouling organisms have higher density and modulus of elasticity than water. They increase the effective thickness of the dome wall. As a result, they ' increase the reflection and decrease the transmission. The sound produced thus gets camouflaged.

1.6 OFFSHORE VESSELS FIND THE ENEMY OFF PUTTING

Offshore oil rigs are appearing on the seven seas and all the countries are bent upon exploiting their resources. Like Gattu of advertising fame the barnacles sing out in unison, "any surface that needs painting is good enough for our settling". The intensity of fouling on these offshore oil rigs is very heavy. The calculations of the strength of these structures below water have often proved extremely erroneous and It. resulted in vulnerable structures. .

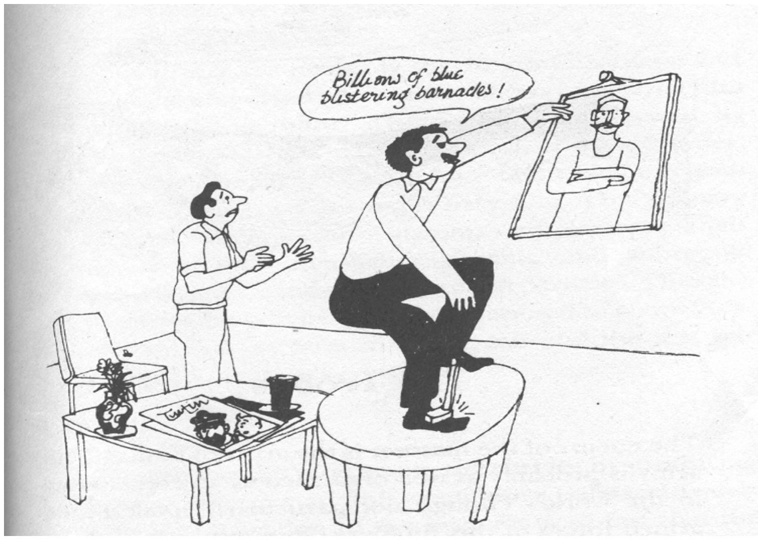
Marine growth increases the sectional area of a structure. The surface characteristics of the structure alter adversely by increased resistance to waves and underwater currents thereby increasing the load applied to the offshore structure. The knowledge about the extent of fouling encountered on such structures is limited, but, needless to say, no offshore structure is immune from fouling.

1.7 THE ENEMY'S EMBARGO ON SEA-WATER

The fouling animals like barnacles, green mussel’s oysters, hydroids and tube worms find sea-water inlets on board ships good receptacles. They grow in abundance in these systems since these are always situated below the water-line. The result is a decrease in tube diameter and an increase in impingement velocities. The fouling mass, if detached during operation, blocks the valves and orifices and starves the system of sea-water.

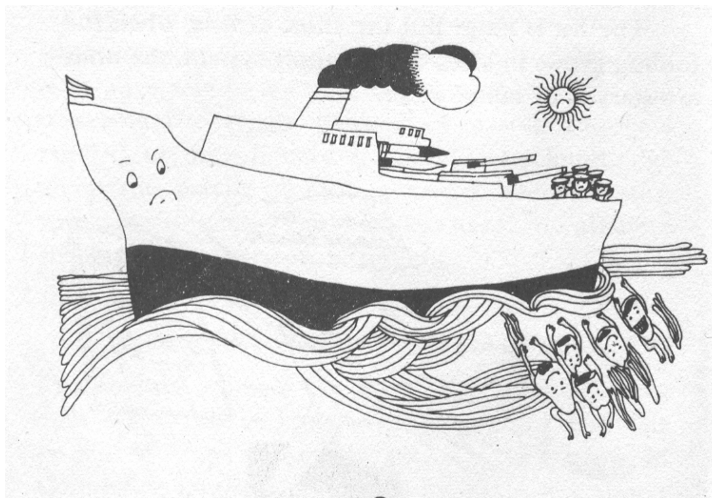
The problem of conduit fouling is multiplied several times in the case of thermal and atomic power plants utilising sea-water for cooling the system. The amount of fouling deposited in such huge sea-water tunnels is enormous. One of the power stations in New England, in the U.S.A., claimed to have removed 266 tons of fouling debris accumulated just in on year. Accumulation of dead shells in another tunnel was of the order of 3-6 feet deep like a luxury carpet in millionaire's mansion. A mat of green mussels two Inches thick was recorded by an electric company in less than six months.

The list is long. But the short of it is, when the fouling grows in a sea-water supply system, the units are starved of saline water.



You're reading too many comics these days, Raju!

2. The Troops



The enemy of the mariner is the army of foulers. This army is probably as well organized as any other army: n the world. Though not particularly modern, the f armed forces of this fouling community can easily be grouped into three main divisions, viz., the infantry, the cavalry and the artillery. The infantry forms the front line forces consisting of soldiers like the bacteria, diatoms, protozoans, algae and bryozoans. The cavalry consists of sea anemones, hydroids and tunicates. The artillery comprises the armoured vehicles or the MBT-mussels, barnacles and tubeworms.

2.1 THE INFANTRY

This is the largest single force of the fouling community. It consists mostly of microscopic forms like bacteria, diatoms, the unicellular algae, protozoans and bryozoans. Though smaller in size, these forms are far greater in number than all the other forms.

Bacteria are probably the foremost settlers, and a surface immersed in sea-water shows a bacterial film within half an hour. These are soon followed by diatoms which are equally abundant in sea-water. Together, they form a composite film which has been popularly defined as the primary film. This primary film of bacteria and diatoms supplements their structure with non-living organic and inorganic detritus, mud, sand and suspended particles. Thus the primary film is believed to be composed of about 20% organic matter, 60% insoluble ash and the rest salt deposition from sea-water.

2.1.1 Bacteria

The bacteria get attached to the surface by producing several adhesive strands containing polysaccharides. The multiplication of the bacteria is so fast that the population on the surface doubles every four hours! Thirty-seven kinds of bacteria have been identified from a fouled surface of which as many as 70% have the ability to get attached to the surface.

The role of bacterial film in a fouling community is (i) to act as attractant to higher fouling forms, (ii) to destroy or alter the toxic property of paint film of me surface and (Ill) to act as agent thermal decay in critical sea-water condenser systems. The last named. Has received a very wide attention in recent years with' 1 the development of OTEC (Ocean Thermal Energy Conversion) energy as an alternative to the 1 conventional sources of energy.

In the OTEC system, loss of heat is regarded as highly undesirable. The system operates on the principle of thermal gradient present between surface waters and deep layers of sea-water which may be. Between 10° to 20°C. The efficiency of the system, . therefore, depends upon the conservation of the thermal gradient which is adversely affected by the bacterial film. The prevention and removal of bacterial. Film is thus a primary concern in an OTEC system.

2.1.2 Diatoms

Diatoms, like bacteria, are microscopic forms, but in size they are much bigger than the bacteria. Bacteria are heterotrophs and so utilize organic substances present on the surface of the substrate to prepare food. The diatoms, on the other hand, contain chlorophyll and produce their own food in the presence of light. The abundant growth of diatoms . On structures not very deep down in the oceans is thus primarily because of the availability of light.

The diatoms have walls made of silica which are. Resistant to most concentrated acids. the diatom film. Acts as a modest barrier to the movements of toxins from the paint film applied to underwater surfaces The surface, made less toxic by the film of diatoms, becomes more favorable for further fouling. In addition, many diatom species form the fodder for the fouling forms. The gut contents of various fouling species have shown the presence of not less than 25 e types of diatoms thus indicating their nutritional role. Diatoms, though not a direct cause for concern, act as precursors for later settlers.

2.1.3 Protozoans

These unicellular forms are microscopic animal species encountered on submerged surfaces. They have no important role to play in aiding subsequent e fouling except that they too form an identifiable group of the fouling community. In number they may not exceed either bacteria or diatoms but they utilize this primary film for firmer attachment.

2.1.4 Bryozoans

Beautiful bryozoans are the brave buccaneers of the , battling barnacle forces. They are brave because they fight against the toxicity of copper-based paints, a quality not exhibited by a majority of the other fouling species. In fact, these species have often been called”the copper-loving organisms".

The bryozoans are animals lower down in the order of evolution and are also known as polygons. There are as many as 3000 marine bryozoan species. At least 150 of these have been found to foul the underwater surfaces. The bryozoans are colonial species. The colonies grow directly over the surface in distinct patches encrusting the affected area or in surface.

A non-biologist, looking at the bryozoan colony, may often call it a coral when it grows out in a fan-like form. Depending on its growth characteristics the bryozoans are called encrusting, erect, calcareous or stolonoid.

A bryozoan, Watersipora cucullata, found in American waters has been regarded as the most resistant to copper poisoning.

Battling with the bryozoans, therefore, needs a different approach and requires a better understanding of their tolerance to toxins.

2.2 THE CAVALRY

The cavalry force of the fouling community consists of sea anemones, hydroids and ascidians or tunicates.

2.2.1 Sea Anemones

A sea anemone probably attracts more visitors in any aquarium than most of the fishes. It grows in water showing off attractive colours and ahead with a Whorl of tentacles. The whorl reminds one of the, inflorescence sunflower and is beautiful to behold.

A fouling anemone is unfortunately a nuisance, particularly for surfaces like navigational buoys, sea-water inlets, mines, etc. The animal when in water, blooms into beautiful flower-like shape, but once outside the water it contracts into a minute ball hardly a. centimetre or two in diameter. Its adhesion surfaces with the help of a basal disc is so firm that it is not easy to dislodge it. Its flexible body adds to the difficulties. The young ones of the sea anemones are free moving larvae which have the capacity to remain in this infantile stage for as long as 30 days. This force of cavalry thus remains trotting in water until an acceptable surface is available.

2.2.2 Hydroids

These are also sea anemones, except that they do not live solitarily but form a colony of their own. Their colonial rule extends to a vast variety of surfaces. In fact, no surface can escape their onslaught. In many cases, the fouling community is totally dominated by these tree-like hydroids. The colonies of hydroid Tubularia attain lengths anywhere between 6-12 inches and develop into a dense tangled jungle acting as excellent receptacles for mud and silt.

The colonial hydroids exhibit a different life cycle from that of anemones. The young ones of these hydroids resemble miniature jelly fishes, swarming the ocean, searching for suitable substrate for settlement. They are more sensitive to copper toxicity and hence do not appear unless the poisonous effect of copper is nullified to some extent by other resistant species.

The hydroids, by their dense colonial growth, greatly add to the natural weight of the surface. It is believed that several pounds in weight is added by this group for every square foot of the surface they inhabit. From the number of fouling species recorded, a majority of known hydroid population appear to have the habit of fouling. The species is ubiquitous in distribution, and is universally regarded as the greatest nuisance

2.2.3 Tunicates

The tunicates or ascidians are also soft bodied forms. They may lead a solitary life, or live in colonies. They are probably the forerunners of man in that they are the first primitive group to show the presence of vertebral column. Their role as fouling organisms, unfortunately, is totally against the interest of man. The ascidians or tunicates abound on almost every surface, moving or stationary.

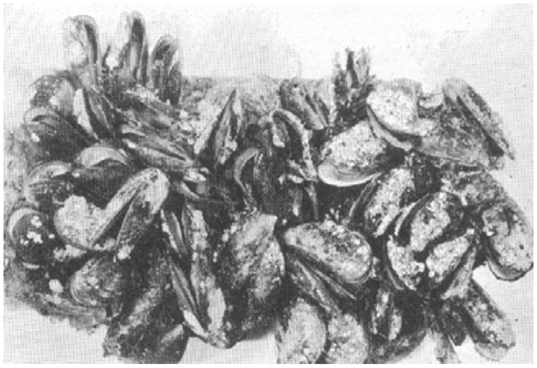
Although they are predominant on all the surfaces, they are not dangerous unless the toxic effects of the protective coating on a surface are reduced. These species, further, are seasonal with less tolerance to variations in the quality of sea-water. They die naturally leaving behind only buds for revival in the next season. Although classified as cavalry forces, tunicates may be likened to the camel forces. Like camels, these animals store water in their body and when disturbed, they squirt out the body water. The tunicates, also known as 'sea squirts', have the best defensive mechanism against the interfering hands of the mighty man.

2.3 THE ARTILLERY

The machines of modern war are represented by MB T or the Main Battle Tank. The artillery corps of the fouling community also comprises MBT, namely, the mussels, barnacles and tubeworms. All the three have one thing in common, i.e., armour of calcium carbonate. The degree of thickness of the armour plates, however, varies with the individual group or corps.

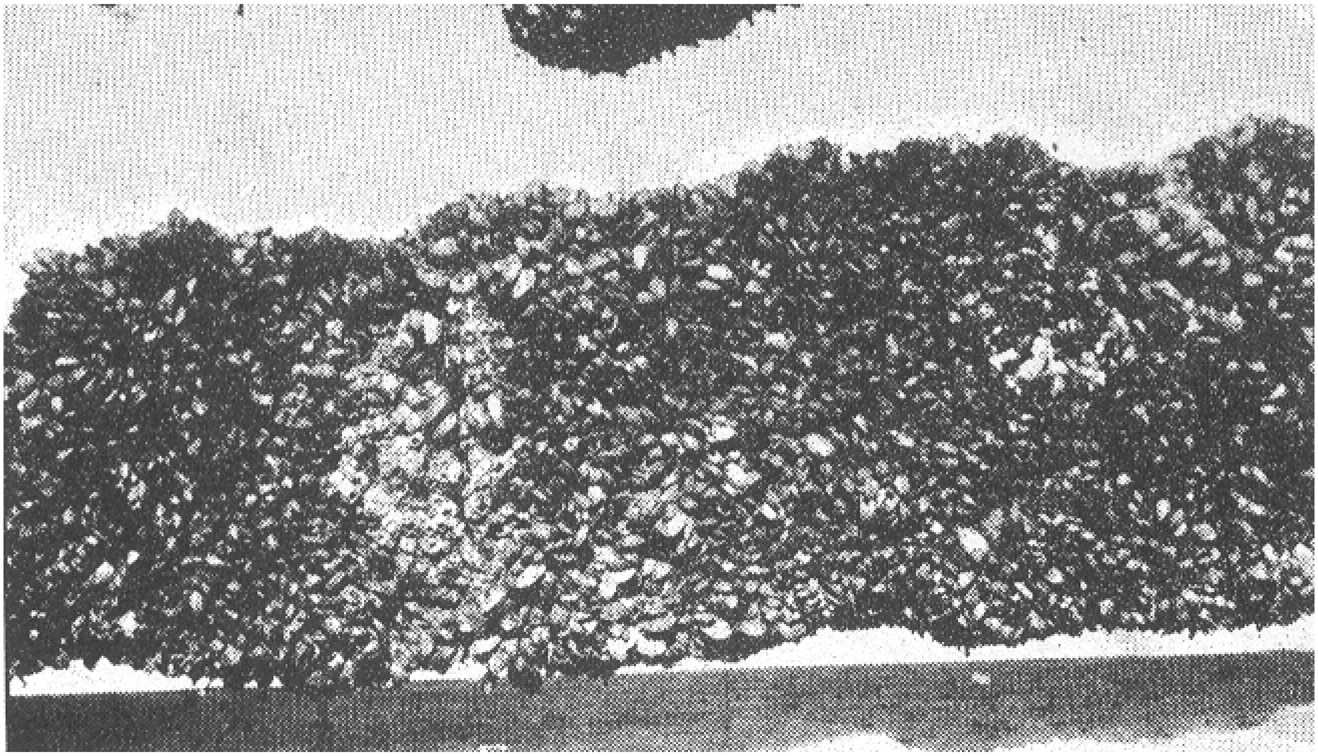
2.3.1 Mussels

These molluscan forms. the delight of the chef and of gourmet, the pride of the princess for oyster pearls, are the primary cause of the plight of the mariner . The mussels, in all their forms. are found on all the surfaces exposed to sea-water. The sea-water inlets, intake tunnels of power stations. etc. are the primary targets of mussels. The mussels. as a group, comprise forms like green edible mussels and oysters. Smaller re mussels like Modulus and Mytilopsis are predominently ship foulers.



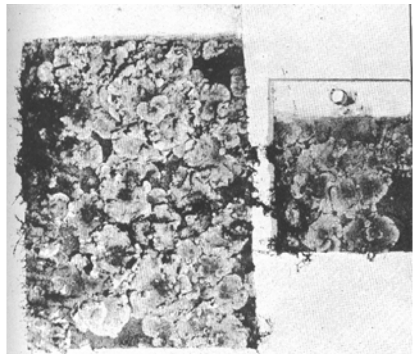
The Mytilopsis sallei is an immigrant species. growing abundantly in the Indian harbours. Particularly at Visakhapatnam. The Hindustan Shipyard there has to remove the fouling debris of Mytilopsis using bucket cranes. Tons and .tons of debris have to be removed as soon as a ship is docked in the dry dock. The growth of this mussel is all over If the surface and when the propellers begin to operate. the calcium carbonate shells are crushed and form a thick cake of white crust. The movement of the shaft is obstructed. resulting in increased fuel consumption.

The settlement of mussels and oysters on a structure represents a permanent stage in biotic succession of the fouling community. The oysters, once settled, remain permanently fixed on the surface The mussels retain their mobility even after they settle on a surface. If a surface becomes undesirable for the mussels, they simply pack off and move over to a new area. This is possible for mussels because their 1. Adhesion to a surface is achieved by means of several threads called byssal threads having adhesive pads on their tips. A mussel secretes either a few byssal threads or many, depending on the firmness of its adhesion.



In a dry dock, the bottom of a ship can be cleaned of the entire mussel fouling but the byssal threads remain on the surface. Cleaning up of these flexible byssal threads is the nightmare of the workforce employed for the job.

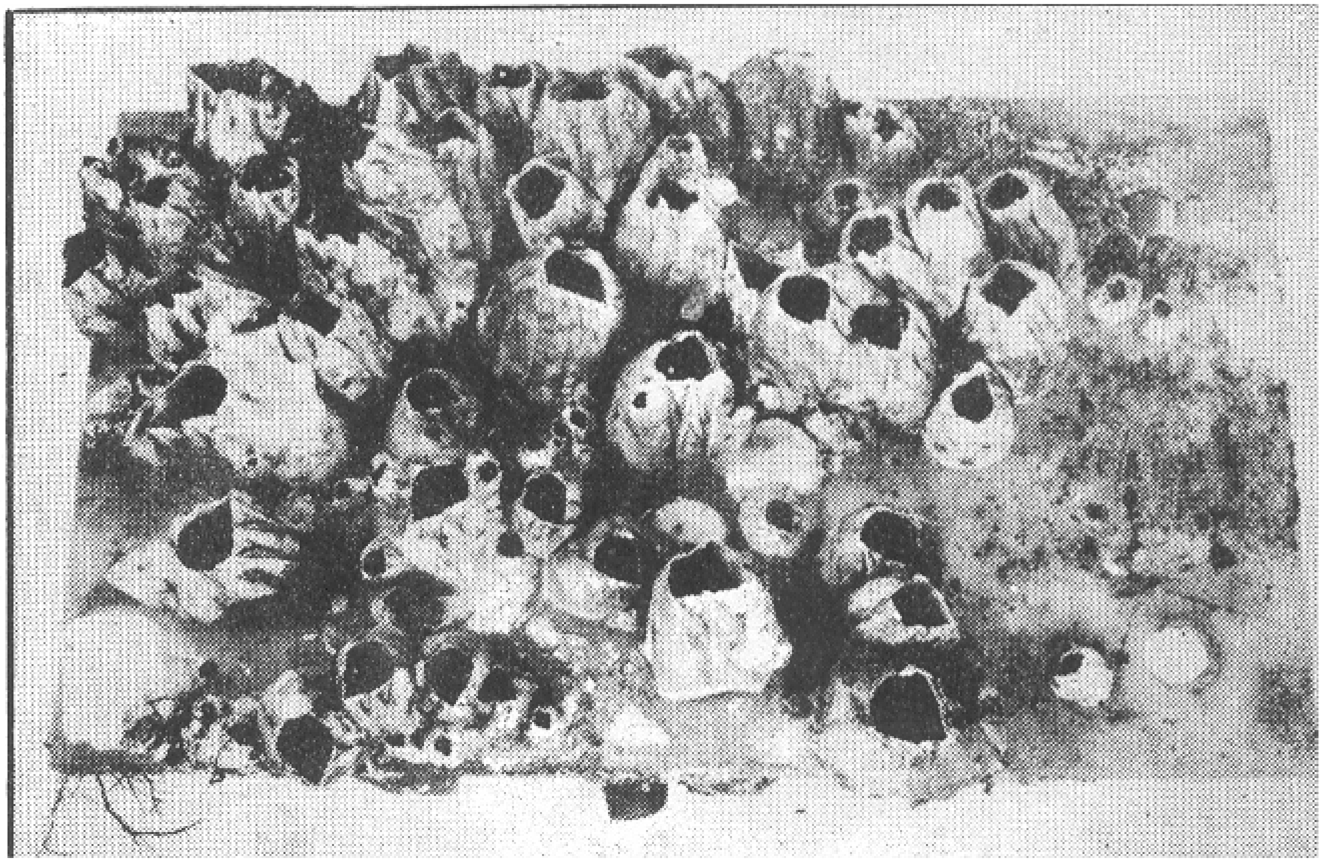
The mussels adhere to metal surfaces when available but when space is at a premium they attach themselves to the shells of other mussels. As a result, the fouling by mussels is multi-layered. On a moderately fouled navigational buoy, if the fouling is two inches thick, the heavily fouled buoy presents a mat as thick as six inches. A relationship between the thickness of mussel fouling and the weight of animals in air has been established. The mussel fouling increases in bulk with the period of exposure. The rate of accumulation of edible mussel has been recorded to be eleven pounds per square foot, per year. This rate, however, varies with the geographic locations, the mass being less in temperate waters and more in tropical waters.



The mussels have an armour of bivalve shells made of calcium carbonate. The animals open their shells at will and close them when conditions are unfavorable. In addition, the ability of a majority of forms to move freely makes this group the most dangerous of the fouling species.

2.3.2 Barnacles

A calcium carbonate mausoleum at Agra, the Taj Mahal is the eighth wonder of the world. Another wonder, also calcium carbonates creation; called Barnacle remains unsung because it is not a creation of man. Shah Jehan had to import vast quantities of marble to build this memorial for Mumtaz, while the I barnacle obtains all. the calcium carbonate required for its shell directly from sea-water. The shell of a barnacle is a mausoleum after its death but is a place when alive. It has an inbuilt mechanism by which it repairs the structure as soon as it is damaged. The architectural beauty can only be understood when looked through an electron microscope and the engineers of modern times may never cease to wonder at its intricate mechanism. The barnacle attaches itself to a substratum by secreting wonder adhesive called cement, which polymerises and hardens even in the presence of water. Man with all his intelligence has et to produce anything even closely similar to this adhesive. No adhesive produced by man can polymerises and harden in water, and, that too, on a surface without any prior complicated preparation. Any injury. to this firm, adhesive base of barnacle is repaired by immediate secretion of fresh cementing fluid. The barnacle presents wonders beyond comprehension of any hi-tech technologists.



The barnacle leads a dual life in common with vi most crustacean species. The species, closely related to prawns and lobsters, produces millions of free in swimming larvae. After undergoing several stages of development, also known as the stages of dl metamorphosis, the young one going under the alias. of cypris, finally selects a surface, secretes its requirement of cementing fluid and gets transformed bc into the permanently fixed, non-metallic form known of as barnacle.

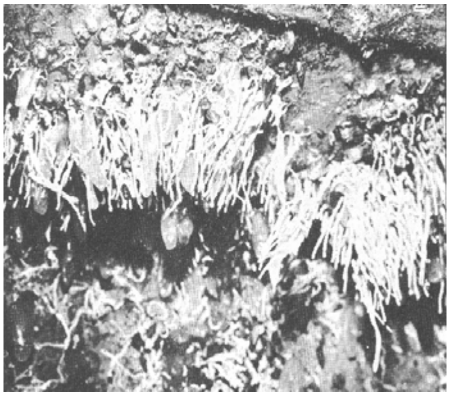
The attachment of cypris to substrate follows a in physical phenomenon peculiar to barnacles alone. The ac foremost legs or appendages of the cypris larvae end in a small cup. This cup at the distal end of the, antennule seeks out a suitable surface and attaches T. itself. Once the selection is over, this cup acts as a, vacuum pad, and holds the animal larvae firmly against all tides and turbulences. The special cement glands in the body now secrete the cementing fluid which passes through specialized canals or ducts to the tip of the adhesive pad where polymerisation and hardening of the base occurs. Once the larva is firmly secured, it loses its mobility and becomes sedentary. A shell is formed on the outside of the animal for protection against predators.

Dr. Karande and his associates at the Naval Chemical and Metallurgical Laboratory, Bombay have studied the life cycle of barnacles extensively. The barnacles studied by the scientists bear such musical names like Balanus tintinabulum, Chathamalus withersi, Balanus communis, Amaryllus euamaryllus, Tetraclitella karandeii. The study has enlarged the while the biologist in Dr. Karande cried out in anguish in a poem called "The Barnacle song".

The barnacle may be nature's wonder or a poet's delight, but to a mariner, it still remains his most IS important enemy. It is true that eras have changed, but the battle in the arena of fouling still goes on .d between barnacles and the boatswain. Any mechanism of protection against fouling is not regarded to be totally effective unless the barnacle community is included. The protection against barnacle is the final achievement for a developmental chemist.

2.3.3 Tubeworms

The turrets of the tubeworms form the final forces of the marine battling troops or MBT. The tubeworms are tender but tenacious. They are extremely tender but still defy the mighty man. The tube secreted by to the animal, unlike the other two forces of the MBT, and is very fragile. But when it comes to settling, the animals settle even in areas normally less acceptable to the other two. Tubeworms are the main foulers of for the propellers made of bronze which create such turbulence that others may lose their foothold. But not the tubeworms. They fear neither turbulence nor have pollution. Once settled, they continue to attract more The and more worms, taking a joy-ride on the merry-go-round of the blades of the propellers



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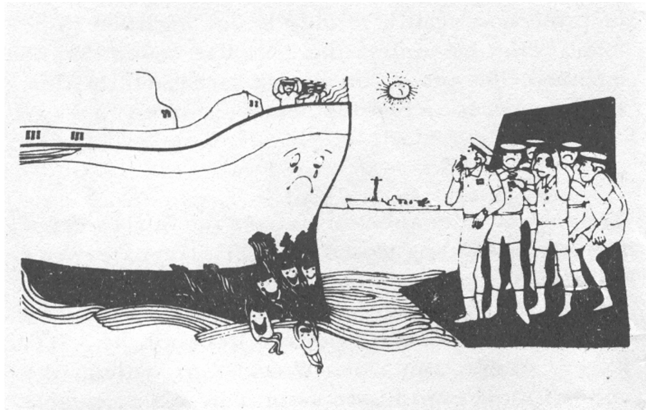
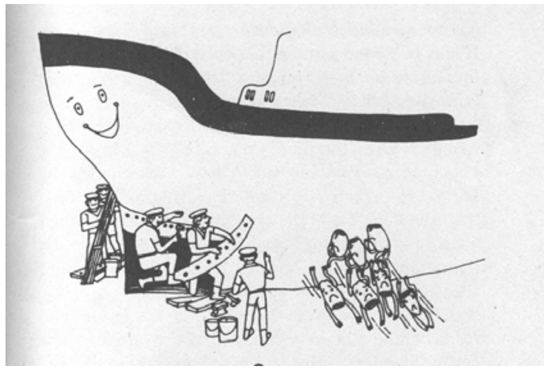
The earthworm, a distant relative of tubeworm, , has shown its benevolence to mankind by aiding in d the fertility of the soil. The tube worm, on the other hand, has shown its malevolence to man-made ~structures, moving or stationary .Neither the high velocities of water at the intake tunnels nor the depth of the deep oceans stop them from settling. Their role in fouling of marker buoys or sonar domes is no less than that of mussels.



3. From Columbus to Cuprous Oxide



History, unfortunately, does not ten us when man built his first boat. But the Bible, probably is the first book to write about a boat. Noah is believed to have sailed in a boat large enough to accommodate a couple each of all animal species which he carried to save them from destruction by the Great Deluge, and thereby to ensure their perpetuation. Either Noah was a genuine biologist who recognised and carried the foulers for survival, or the underside of his ark itself had foulers which blossomed in great vigour once the difficult period was over!

In Indian mythology thousands of years ago Lord Raffia travelled in a boat sailed by Guha, King of the fisher folk. The writer of this epic, Menarche Valmiki has not mentioned the state of the keel of Guha's boat. t may be fair to assume that even during this period fouling must have plagued the poor fisher folk. History is full of saga and tales which suggest that large fleets of big ships sailed the oceans on very long voyages. One thousand years before Christ, the Phoenicians were believed to have circumnavigated Africa to reach Cornwal in Britain for their requirements of tin. Ancient Egyptians had built their boats spanning not less than 160 feet. People in early civilizations not only had big fleet of ships but they also fought battles for securing superiority over the seas. The naval ships of this era or the huge merchant vessels could not have escaped the wrath of these marine wonders. Ships had to be brought on shore to lean their underside of fouling even during the voyages of Vasco da Gama and that great discoverer, Columbus. The early man did try to fight the foulers with whatever limited forces were available to him

3.1 EARLY ARMOURS

The ancient mariner sailed ships with wooden hulls. He had to face the dual enemy, fouling and wood boring. The predominant marine wood boring organisms are worms popularly called teredo. These teredoes have been appropriately compared with torpedoes because they drill holes in a wooden plank through and through. At least one voyage of Columbus had to be abandoned because teredid worms had eaten holes in his ships. Till the advent of steamships man had to combat the dual enemies, the fearsome fouling and the terrifying teredids. Needless Oat. to say the war then was between warships and the woodworms

The earliest voyager used tallow on the surface that of the hull to act as a deterrent to the destructive teredoes. The effect of the treatment was short-lived. the Ancient Phoenicians and Carthaginians were believed to have used pitch for the protection of the keel of wooden boats. Other countries tried treatments like heir wax, tar and asphalt on the underwater surface. These treatments had an additional function of giving they adequate watertightness, extra structural strength and the smooth sailing in water.

The Vikings of the tenth century painted their boats above the water-line but not in the region the immersed in water. Although in one of their tales, a small boat was protected from worms by "seal tar", such treatments do not appear to have been the m. common practice. Pitch sometimes mixed with tar, oil, resin or tallow was fairly popular during thirteenth to fifteenth centuries for underwater protection. Thus the great Venetian fleets operating during the fifteenth century used tar for the underside.

The ships in which Columbus sailed were similarly lese protected with a mixture of tallow and pitch. This however, did not discourage barnacles and teredoes and every few months they had to be brought ashore of to remove fouling. The Portugese, on the other hand charred the outer surface of the ships to a depth of It of several inches during the early fifteenth century. In the fact, the ships used by Vasco da Gama were protected in this fashion when he sailed off to search for rich India. The British also built one vessel Royal Williams entirely from charred wood in 1720.

As the European world realised that the earth. Was not flat as decreed by the Church and the desire to search for silver and gold became a passion, the ships became bigger, the fleets larger and the voyages longer. The meager protection offered by treatments such as tallow, tar, pitch and oil became impractical. The tallow war became a shallow war with barnacles still remaining victorious

3.2 ADD-ON ARMOUR

The second stage in the war against worms began with the protection of the keel of the boat with a protective sheath. The most primitive type of sheathing is the use of animal hides on the underside. The hides, hair and oils were subsequently covered by a wooden sheath so that the planks of the boats remained intact. However, this increased the cost of boat building.

3.2.1 Lead the Leader

The revolution in the sheath war came with the introduction of metal sheathing for the underwater hull. The first metal to be tried extensively was lead.

The ancient Greeks, known for their art and sculpture, for their gods and goddesses were also known for their scientific temperament. When all the other nations were still struggling for a suitable remedy for woodworms, the Greeks protected their ships with lead sheaths as early as 300 years before Christ. Archimedes of Syracuse who ruled between 287-212 B.C. has his ships sheathed with lead and fastened with copper bolts.

The Romans subsequently used lead sheathing in the third century before Christ. The lead sheathing was attached to the hull by means of copper or gilt cal. nails. Incidentally, even at that time an insulation of paper or cloth was provided between the two metals. Many Roman ships with their lead sheath in good condition have been recovered.

In more modern times, Leonardo da Vinci designed a rolling mill for making sheet lead in A.D. 1500. Spain adopted the lead sheathing first; followed by France and England. Charles the II in fact ordered that no other types of sheathing should be used on His Majesty's ships. Thus *HMS* Phoenix and some twenty other ships of his time were protected by lead sheathing.

The lead sheathing, a process popular with prominent ship building states for centuries, however was found to have a corrosive effect on rudder iron . and hence these ships became unsafe for voyages In 1668, when Sir Thomas Allen set out to attack the Algerians, he specially requested for ships without lead sheathing. He felt that the ships will be so encumbered that they would not be able to overtake the light, f1eir unsheathed enemy vessels. Further, they very much tore retarded the ship's course.

3.2.2 Copper- The Brown Battler

The lead sheathing had a very poor antifouling property though it served as a physical barrier against the teredid ship-worms.The antifouling properties of copper became known subsequently. Thus copper came into widespread use and replaced the lead sheaths.

The beneficial properties of copper have been known to Indians since early ages. Ancient Phoenicians and Carthaginians were believed to have used copper for sheathing their boats. It is, however, not clear if copper sheathing was used by the people of ancient times and why it was discontinued. Even in the tenth century B.C., copper foundries existed as evident from recent excavations.

The first patent on use of thin copper sheet as antifoulant was filed in A.D. 1625. Another patent was filed in the year 1728 for a method of sheathing and preserving the planks of ships, but still the commercial use of these patents for ships had not been reported.

In 1758, a British ship HMS Alarm was sheathed with thin copper on an experimental basis. This 32-gun frigate after its voyage to the West Indies, reported that the planks of the boat remained free from ship-worms. The bottom was surprisingly totally free from any fouling. The cost factor worked out to be equal to the wooden sheathing employed earlier. The ship's report proved that copper protected against teredid worms, was not injurious to the planking and it did not support any fouling. The British navy accepted the lull usage of copper sheathing since then.

The Americans adopted copper sheathing in t 1781, using it for their frigate Alliance. The success of copper sheathing was soon accepted by all maritime countries. The French even built a submarine protected with copper plate in A.D. 1801 for their emperor Napoleon.

Early ships sheathed with copper were fastened with iron nails. But severe corrosion of iron induced, the latter models to use copper bolts for fastening the sheath. Still, the wear of copper metal was heavy and became cost prohibitive. The problem was then referred to the council of Royal Society. Sir Humphrey ; Davy suggested in 1824 that attaching apiece of zinc f size as small as a pea could protect at least 50 sq. inches of copper. The Admiralty reluctantly agreed o use zinc studs to protect copper in lieu of iron.

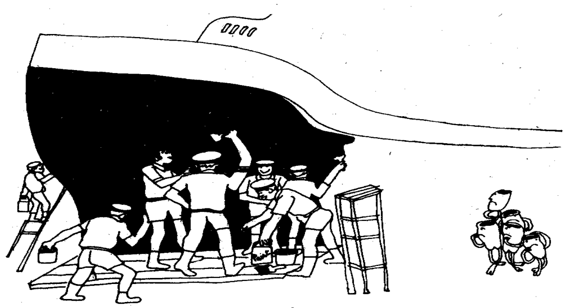
For all its efficacy in protecting copper from dissolution, this method resulted in excessive fouling. Although, now copper was protected, copper could not protect itself from fouling. The battling brown warrior felt as if its fangs had been removed. However , by this time, steam ships with iron hulls came into vogue and further experiments with copper sheathing were discontinued.

3.3 ANTIFOULING PAINTS

Ships with iron hulls came into vogue in the late eighteenth century, and in 1810 even the British Parliament discussed building naval ships with this metal. The size of ships increased tremendously as also their width. Both battle ships and merchant vessels became bulkier

The battle with barnacles was renewed since even these iron bodies did not insulate the vessels from fouling. The age-old adversary continued to attack the modern ships. The problem was intensive and the solution elusive. The battle was lost almost before it began. The copper sheathing used for ships like HMS Jackal and HMS Triton resulted in heavy corrosion of the plates. In fact, the commander of HMS Triton conceded that the iron plates were virtually held by its foe, the fouling. As a result, in 1847 the Admiralty even contemplated doing away with the use of iron ships. However, better sense prevailed and better brains started searching for a suitable solution.

4. The Elusive Solution



The search was on for a suitable substitute for copper , perhaps a mixture of copper and some poisonous chemicals. As early as 412 B.C. it was known that a mixture of arsenic and sulphur in oil applied on the hulls permitted smooth sailing of the ships. However, oils and waxes would not do for these war ships. A better method was to incorporate some such compound in paint or varnish and apply it to these ships. The search thus began for the killer of the fouler, a war paint also known as 'antifouling paint'.

Every chemist and physicist worked overtime to produce an ideal compound. By the year 1865, as many as 300 patents were filed in Britain alone. Many of these compositions were nothing but cranky suggestions. Admiral Belcher felt that these compositions were designed more for fouling settlement than for acting as antifoulants. The antifouling paints developed a disastrous reputation and sailors were offered ten shillings for every magnificent specimen of mussels recovered from British ships painted with these chemicals.

The solution for the woes of the chemist was found in the brawn of the brown warrior-copper. Containing copper sulphate, and was applied when hot over a quick drying primer paint. Another hot plastic preparation called the "Italian Moravian" became so popular that this composition was followed even in the present century.

A large number of chemicals other than copper, mainly arsenic, mercury and its various salts were also tried. The matrix for the paint included linseed oil, shellac, tar and various resins. The solvent varied from turpentine to benzene. Whatever be the composition, it was recognised even at that time that these coatings should supplement a prior anticorrosive paint since these ships, unfortunately, had to combat a dual problem of corrosion and fouling.

The battler copper failed as a sheet anchor for iron vessels. The brawn of copper had to be supplemented with the inventions of the brain of the scientist. Since, for most of the learned community fouling was an insignificant problem, they did not deem its study befitting to their status. The scientific research thus remained incomplete, probably due to lack of any experimental investigation. The problem was, however, widely discussed among the naval officers, naval architects and ship builders who were die worst affected.

The first organized paint research was undertaken by the U.S. Navy in 1906. The study consisted of exposing commercially available compositions to underwater immersion tests. The procedure was time consuming while control on quality was found wanting. No two paints behaved alike and this was known only after a period exceeding six months.

This state of affairs continued till the advent of second World War. In 1939, through a joint effort of a premier oceanographic institute and a naval shipyard in the U.S.A., the composition of the hot plastic compound was broken down and each component ingredient identified. The study revealed that commercial manufacturers resorted to increasing the number of ingredients which had no role to play in the protection of the surface. The need to search for suitable ingredients for the best antifogging composition began by employing both scientific experimentation and naval ship trials.

The first and foremost fact to be established was that any antifouling paint is effective only as long as the toxic component of the paint comes out in water in a dissolved state. The second factor essential was that it should have a broad spectrum toxicity so that fit is uniformly effective against the foulers ranging from bacteria to barnacles. The third parameter necessary was its capability to mix in almost all proportion with the other ingredients.

It is now established that copper compounds the generally meet all the requirements for antifouling paints. Out of the six salts of copper, cupric citrate was highly soluble in water while cupric oxide the sail least. Both these compounds were therefore eliminated. Cuprous oxide, on the other hand, was cap moderately soluble in sea-water and could retain its potency for long periods. Cuprous oxide thus became the most acceptable toxic component to the navies of the world.

This copper compound is now incorporated in the matrix or basic ingredient of the paint. In the conventional systems this matrix is composed of rosin. Rosin is a naturally available acidic resin which dissolves in water. The patent poison incorporated with such a matrix will leach out in the sea-water along with the binding ingredient, When both the toxin and the matrix dissolve in water, the paint film loses its strength and film properties. In order to ensure that the film remains intact, the matrix is further supplemented with neutral material and plasticisers. Both these constituents give enhanced mechanical strength to the paint film. Antifouling paints containing the, new war weapon, cuprous oxide, in concentrations ranging from 30-50 per cent by volume sounded the death knell for the combined army of the fouling forces. The infantry proved ineffective since they could find no foothold on the paint. The forces searching for surface as sheet anchor succumbed to the mighty might of copper. The mussels, barnacles and tubeworms-the triumvirate of MBT attacked relentlessly, secured their foothold but perished in the solution of sure-fire cuprous oxide.

The ship builder was happy that his ships now sailed safely. The dockyards did a brisk job of adorning a large number of ships with this magic formula. The captain of the ship, the ship builder, the naval architect and the deck hand all heaved a sigh of relief that the mighty brigade of barnacles had been humiliated.

But was that so?

5. The Western Command

No sir. The battle with barnacles had not ended. The fearsome foe of the fighting armada, this community of fouling animals, continued to terrorize the mighty mariner. Momentarily foxed by the machinations of mankind, this indefatigable enemy continued its relentless attack. This ships sailed away in supreme confidence but trudged back to the dockyard vanquished by the valiant forces of the fouling species. The crowning glory of copper failed to protect the hips even for a single year be it English, American or Indian.

5.1 MARCH FROM MIDNIGHT

The midnight of the 14th August 1947 saw the lowering of Union Jack at the Red Fort in Delhi and the fluttering of the National Tricolour to herald India's independence. The first rays of the sun fell on the tricolour proudly flying over the helms of the Naval ships in Bombay harbour on the morning of 15th August 1947. The Royal Indian Navy became the Indian Navy while inheriting the ships of the British Navy. The maintenance and the upkeep of the ships thus became the responsibilities of the engineers and the technologists of this young fleet.

Chemical and Metallurgical Laboratory (NCML) at Bombay and Naval Physical and Oceanographic Laboratory at Cochin were set up to provide the scientific support to the growing Naval force. The Naval Chemical and Metallurgical Laboratory had it inception in a most unpretentious building reminding of an underground air raid shelter. It was here that in the formative years, the laboratory found solutions to the day-to-day problems faced by the ships in the field of metal failures and chemical testing of fuels used on board ships. Till 1961, the scope of the its laboratory remained limited to providing just a scientific support to Naval ships. But in 1961, the yard laboratory became a part of the Defence Research and Development Organization and began undertaking the challenging tasks of developing technologies suitable for Indian conditions.

The ships were inherited from the British Navy and so also was the technology .The experience of the ship staff with such materials was disheartening. The technologies developed by British scientific and community for British ships were found to be inadequate in the tropical climate of India.

This was more true in respect of underwater protection of ships. The ships protected with paints developed at Admiralty showed fouling settlement within a short period of time (often as short as six months. The situation can be compared with that existing during the days of Columbus, when he had to beach his boats frequently to remove fouling. The ships of the Indian Navy too met a similar fate, with ships needing dry-docking frequently. Dry-docking facility being at a premium, the problem of bringing ships more often for cleaning the underside became a matter of grave concern for the managers of dockyards. The result was a large number of ships waiting for maintenance. The managers of the dockyards looked up to the scientists of this small laboratory to develop a paint giving a life of at least one year. The challenge was thrown to NCML and an interdisciplinary approach to develop antifouling paints was planned, using the expertise of both the biologists and the paint technologists.

5.2 FOULING IN INDIAN WATERS

The first and foremost task of the biologists was to understand and study the behaviour of foulers abounding in Indian waters. The study of the behaviour of fouling organisms, the types of organism prevalent, habits and behaviour of settlement thus became the foremost task of the marine biologists engaged in fouling research.

The study revealed an interesting observation. Fouling in British waters was primarily restricted to a few months during summer. In India, on the other hand, it was a twelve-month phenomenon irrespective of seasons. The temperatures in these waters showed no extreme variations and hence the productivity was extensive. Another parameter, namely salinity, showed a greater degree of variation during monsoon months. Although, this restricted the settlement of some groups of foulers, it facilitated the growth of other groups which tolerated lower salinities.

The intensity of fouling growth in Indian waters can be realistically understood by computing the average biomass production in India. The biomass production is calculated by determining the weight of the fouling debris on a surface per unit area per year. At the Andaman Islands this biomass was recorded to be 8.0 kg per sq. metre per year, so also near Madras in the South. This figure in the near-shore water at Bombay was about 5.0 to 6.0 kg per sq. metre per year. This when compared with the values recorded elsewhere, such as at Florida in the U.S.A. (3.0 kg), Hong Kong (5.0 kg) and in Argentina (0.5 kg), shows the extent of fouling in India. Here the ruling factor is the Darwinian principle of the survival of the fittest.

This biological evidence was enough to convince the paint technologists that the paint formulation developed for temperate waters would not prove effective against the foulers in Indian waters. No wonder the managers of the yards in India were a harassed lot.

5.3 INVESTIGATIONS

Every time a ship came back to the dockyard before scheduled docking period, the managers of the yards turned red with fury. For them every ship returning for dry-docking in this fashion was extremely upsetting the schedule and requiring more over time for the dockyard staff which even otherwise was hard- pressed. The meeting between the managers and the men of science of the laboratory could not explain why ships should come earlier than claimed by the paint manufacturers. The laboratory, therefore, agreed to undertake a thorough investigation into these failures at its modest abode.

A special floating raft was moored at a distance of two kilometers in the midsea, and a large number of panels were exposed under conditions similar to those faced by the ships. The extensive evaluation of the paints used by ships showed an interesting phenomenon. The paints which were designed to give leaching of copper at the rate of ten micrograms per square centimetre of the surface every twenty-four of hours, was giving thirteen micrograms or more every day. The result was obvious. The copper present in these imported paints could not last as long as the manufacturers promised. The copper in the paint dissolved faster but why.

The reason is simple. Just as sugar dissolves less in cold milk and more in warm milk so also the copper in the paint. The dissolving characteristics of every compound change with the temperature of the dissolving medium. The paint containing copper dissolved at a lower rate in England where temperature was low and hence gave a longer life. In India, the same paint showed excessive copper art dissolution because of warmer temperatures and hence gave much shorter period of protection. The answer of hot and cold waters looked so simple that the managers gave up turning red with rage. They now asked the men of letters to let them have an antifouling paint equally good for the ships in Indian la lain waters. A new era in the development of indigenous the .paints thus began from that day.

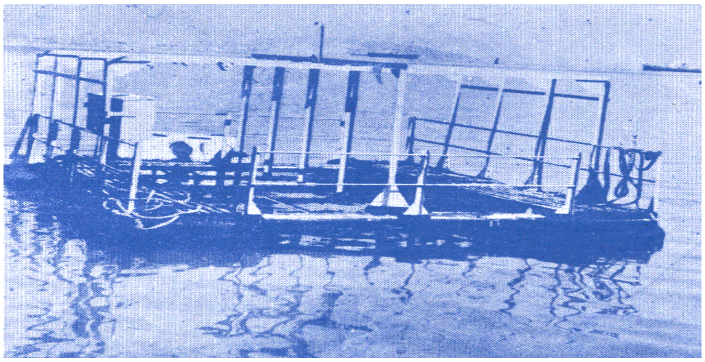
5.4 ERA OF INDIGENOUS PAINTS

The conventional antifouling paint of that time consisted primarily of rosin and a resin, phenol formaldehyde condense. To these two substances to which acted as binder, copper was added in the form of' of cuprous oxide. It was observed earlier that all ting compounds of copper were generally toxic but only cuprous oxide when mixed in paint formulation per possessed good to moderate solubility. The toxic effect our of copper used in the form of cuprous oxide remained effective for extended periods of time. The rosin and It in phenol formaldehyde condensate together formed the matrix or vehicle of paint which gave the paint its required toughness. The painted surface when exposed to sea-water would allow the leaching or dissolution of copper. The dissolution rate of copper in the paint was critically dependent on the resins which formed the vehicle. If copper dissolved faster, the paint failed; but if it dissolved at a slower rate, it per was less toxic to the fouling organisms.

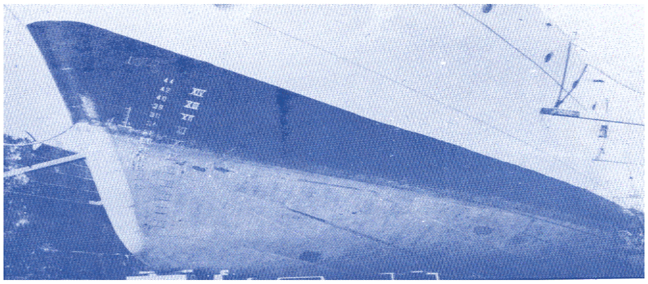
Controlled leaching of copper, therefore, can be. In attained only when the two resins along with the toxin per are properly balanced. Rosin, however, unlike its and sister, resin, dissolved in sea-water while giving out The copper. Thus there was a continuous depletion of that rosin from the matrix. This prevented loading of paint 'hey. with larger volumes of cuprous oxide because the paint an would fail once the rosin was exhausted. The laboratory could not alter the nature of rosin, yet managed to give a new paint which now lasted as long as nine months under Indian conditions. But the men in the laboratory were rather disappointed that could do no more, what with rosin in the paint joining hands with cuprous oxide and competing with it in dissolving in water

5.4.1 The Virtuous Vinyl

The first effort in indigenous development of antifouling paints was thus only partially successful. What was needed was a better binder than rosin which will not dissolve in water.



The search was on for a better substitute for conventional paints. Past experience suggested that definite selection criteria should be established as a primary step. The most important requirement was that the paint should offer continued protection for prolonged periods without consumption of the paint matrix. Durability of the film, better adhesion, non-corrosiveness and surface smootherness were the other qualities required of the paint. It must also be easy to apply and quick to dry.



All these virtues were found in vinyl. The workers in other countries who were also disturbed by the existing soluble matrix, found vinyl resin a good substitute. for rosin. In fact, this resin had all the conditions demanded of a good antifouling paint: Unlike the soluble matrix type, the new generation of paint could retain larger loading of cuprous oxide pigment without any loss of the mechanical integrity of the paint film. The vinyl had the virtues of mechanical toughness without requiring any additional support, while simultaneously having the greatness of being compatible even with that black sheep. rosin. Many manufacturers used rosin in vinyl resin to increase the solubility of copper and obtain longer life for underwater coatings.

The Indian scientists also thought of using vinyl in their efforts to produce a superior antifouling paint. The hunt began and with the new petrochemical industries sprouting in large numbers all over the country, the task was not difficult; and the search for the vinyl resin was successful. The antifouling paint was now produced with sufficient loading of copper toxin to give the ships protection for full twelve months. The efforts were now accelerated and anew group of paints was developed which promised protection for fifteen months at a stretch. The virtuous vinyl, thus proved a boon to the burdened boatswain.

5.4.2 Stannum the Supreme

But the scientists did not rest on their laurels. They continued their search to better the best and identified in tin a highly effective toxin. Tin, technically known as stannum has been known to mankind for almost thousand years. It is mixed with copper to get superior alloys like bronze and brass and is used in many major industries. Tin is generally non-toxic, but when combined with some organic constituents, it was found that it exhibited a broad spectrum toxicity.

These compounds of tin, known as organo-tin compounds, showed excellent insecticidal, fungicidal antifouling properties. They were studied extensively by Dutch scientists. Commercial paint coatings based on these compounds were developed the sixties, i.e., around the time when vinyl paints became acceptable to the Indian Navy. The scientist of NCML were, however, not lagging behind. They caught on the scent of stannum, and the struggle to develop organo-tin compound based paints indigenously was on. The first task was the selection of a compound most suitable for Indian waters. The search ended with TBTO, or tributyl-tin oxide, commercially known as Bis Oxide.

5.5 POLISH WHILE PROTECT

Towards. late seventies a new concept in the organo-tin antifouling compounds, known as self-polishing, antifouling coating, was developed. Here tin is chemically linked with a polymer chain to give a bioactive material. The commercial production of this bioactive polymeric coating began with enthusiasm elsewhere in the world.

In India, too, the new approach in the protective coatings began earnestly in early eighties. An organo-tin copolymer was developed in NCML laboratory .It was successfully combined chemically with an acrylate polymer. The resultant polymer was used as a coating. The laboratory has already provided such protection on a trial basis to Naval ships.

The organo-tin polymer has been widely welcomed by the mariners all over the world, because it has unfailingly exhibited long-term protection of the underwater hull. A very much needed reprieve was thus given to the troubled shippers. The mechanism of protection by these coatings is totally different from the one given by either the conventional or the vinyl antifouling paints and needs explanation.

5.6 HARA-KIRI

Hara-kiri is a Japanese word meaning sacrificing oneself for the sake of one's country or one's pride and prestige. The new organo-tin polymers also do the same in order to give protection to the ships. In conventional paints protection is given by the dissolution of toxin from the paint at a constant rate, thus resulting in virtually no toxin to protect once the major amount of the toxin poison is released by the parent paint.

But that does not happen in the case of the organo-tin polymers. Here the surface of the polymer reacts with the sea-water. This causes hydrolysis of the polymer binder. The organo-tin moiety (part of the polymer) is released to the sea-water which kills the young fouling animals at the settling stages. The remaining depleted layer of the co~ting has an attraction for water and with no structural and integral strength in the binder; this layer is removed easily by the flowing sea-water.

The removal of the first layer of the polymer coating does not mean that the paint is no more effective. Anew surface with the same effectiveness is exposed for fresh antifouling action. Once this layer is also exhausted, another fresh surface is offered and the process continues. Thus one can say that each layer of this organo-tin polymer coating commits Hara-kiri.

The new SPC coating thus opens a new horizon e in ship-bottom protection which in a limited manner also gives a frictionless surface. Thus the new coating f. saves valuable fuel. It may be highlighted here that f. by self polishing, the paint removes the part of the coating itself to give a better, smoother surface with u time

5.7 FOUL AND BE DAMNED

The battle between barnacles and the battleship has always been fought in the environment created by man. This environment is the release of poison in water to prevent their attack. In the process, other beneficial life in oceans is also likely to be affected as these chemicals do not select enemies, but are indiscriminate in their action. Several countries, with a meagre economic ocean zone, are worried about the building up of concentration of the toxins which may prove harmful to fish and shellfish. There is therefore a growing tendency in these nations with narrow economic zones to restrict the use of toxins beyond a certain limit for antifouling paints. Since ecology and human health are inter-linked, some environment protection agencies try to enforce strict monitoring of the toxic levels in water. But such restrictions tend to give lesser life to paints and strengthen the hands of the enemy of the mariner.

A more recent approach, therefore, is to aim at total self-imposed restriction in such toxic coatings. The effort now is to develop synthetic coatings which are antifouling but non-toxic. There surfaces are either low energy surfaces or frictionless coatings where the attachment is difficult, and the barnacle forces can be removed without much effort. Let the foe, the foulers, settle on the surface, and they will be removed, if necessary, with the help of divers or underwater implements without bringing the ship to dry dock. Fouling is inevitable, so why not let them foul, and we are damned, if we allow them to get a firm foothold.

Part II: Fight against Corroison

6. The Enemy Within

The fouling forces had been foxed. The muscle power of mussels, the shells of the battling barnacles and the turrets of the tubeworms could not make any dent in the ships protected with the new paints. In short, the MBT was now an empty force. The naval architect was appeased, the fabricator was flushed and the “captain of the ship was contented. Alas! Their satisfaction was short-lived.

The ships sailing in the oceans now came back from their voyages with their undersides clean but their superstructure showing ugly, brown stains. The paint on the ships was damaged and the metal beneath was eaten away by corrosion. The damage in this case was not due to any external enemy as in the case of fouling of their undersides by marine organisms but was in-built in the ships.

6.1 CORROSION, THE COMMON CURS

The phenomenon of corrosion is not confined to ships alone. It affects equally the handi of the housewife, the fork of the farmer and the jeep of the jawan. Corrosion of iron is commonly known as 'rust'. All metals are affected by corrosion, though to varying degrees. The only exceptions are the 'noble' metals, gold and platinum.

The product of corrosion is the oxide of the metal. A few molecules of oxygen in the atmosphere strike o the metal and form the first layer of oxide. This oxide layer is so thin that it allows further interaction between the molecules of iron beneath and the T molecules of oxygen in the air. The atoms of metal h: pass through the film as if passing through a sieve to : cause more and more corrosion. The process is w continuous and in no time, the metal crumbles into powder.

The sailor, hanging perilously, laments over his it ill-luck and curses the corrosion while applying a fresh coat of paint. Corrosion, which occurs universally, is selectively severe in and around the sea. Sea-water in all its phases attacks metals more severely than on land or skies above it. The air above the sea is corrosive; the spray mist from the surf zones is even more corrosive while the salt-rich sea-water is much more ail corrosive than others. Marine corrosion thus is a phenomenon experienced by the mariners sir. Irrespective of whether the ships are in water or ' outside. As both ferrous and non-ferrous metals are equally affected by this cursed enemy, the cancer of co metal corrosion, the ship hulls, machinery components, port and harbour installations, all need frequent inspection. The ships have to be dry docked often for repair and, if necessary, for the replacement of corroded hull plates and other worn out an components.

The beginning of corrosion is virtually undetectable. It forms on metals silently and to progresses deep within the metal. Therefore, the first for. Task in containing corrosion is to establish techniques of detection.

6.2 CURE FOR CANCER

The Naval Chemical and Metallurgical Laboratory had thus a further task of protecting the ships and their components from this scourge, in addition to waging war against the underwater organisms. The battle this time was against a force which was not visible while attacking, but whose efforts got manifested when it was almost too late to combat it. The laboratory ,therefore, set up the techniques for monitoring and detection, surveyed the extent if damage, and finally found the solution.

A large number of marine exposure stations were established at important harbors of the Navy to study the rates of corrosion taking place not only in the salt .air but also in the fine mist of the tidal sprays. Corrosion rates were evaluated under laboratory simulated sea-water conditions and also under highly turbulent conditions found near a ship. The vast data generated showed that the loss of metal due to corrosion was 1.5 mm per year in stationary conditions. This rate increased to 6.0 mm when the conditions were dynamic. Such extensive Josses of metals, if allowed, would mean one new ship every five years to keep the country's naval forces healthy and battle-worthy. Are we wealthy enough to afford it? No, of course not. The laboratory after their intensive investigations and research have been able to proclaim "give us the ship and we shall protect it for ever"

6.3 PRIMARY PROTECTION

The actual protection of metal of ships begins at the shipyards. The shipyards receive large numbers of iron plates each varying in thickness from 10 to 30 mm. These are produced in various steel plants and h. transported to the shipyards by rail. The plates In received by the builders are covered by a thick layer of metal oxide called mill scale. The accumulation of rust is accelerated by the cutting of these plates with as oxyacetylene torch for proper shaping.

The first task of the shipyards, therefore, is removal of the mill scale. This hard scale can. Only be removed by bombarding the metal with fine steel shots by a process called shot blasting which forcibly removes the tenacious mill scale. The shot blasting will expose the bare metal which is highly reactive to form unwanted rust unless protected properly. The laboratory came to the rescue of the ship in builder and provided him with a heavy duty primer ca which when applied on the new bared metal gave it adequate protection to last the shipbuilding operation. of This technique has now been accepted by all the major shipbuilding yards in India with great relief.

6.4 PANCHSHEEL FOR PROTECTION

The protection given at the time of fabrication, is just hi enough to last the metal through the shipbuilding process. But It is not a sure- fire treatment against corrosion in the sea. The underwater hulls of the ship have to be protected by a new paint system. The five

.principles of protection or the panchsheel for m ;protection are: good adhesion to metal, (ii) low permeability to water, (iii) good mechanical properties, (iv) resistance to chemicals, and finally (v) compatibility with antifouling paint.

In the development of anticorrosive paints, one has to consider these five principles. The ships of the Indian Navy inherited the paint schemes developed by Admiralty of the U .K. This paint, called ADMAR anticorrosive paint suffered from the same drawback as the antifouling paint developed abroad. The paint was hardly effective in the tropical environment. The first phase of development at NCML centred around the improvement of underwater life of these paints with improved resins. A paint was developed with life-span of nine months to' match the life of antifouling paints

Improvements in the effective period of antifouling paints automatically raised the demand for improved anticorrosive paints. A ship is useless if .it can be protected against fouling for twelve months but has to be docked to remove corrosion! The advent of vinyl in the fight against fouling suggested that vinyl may also be investigated to combat corrosion. Copolymers of polyvinyl chloride and polyvinyl acetate offered encouraging results. Anew anticorrosive paint film which was tough, flexible and highly resistant to all chemicals was obtained. This anticorrosive paint developed by the laboratory after intensive investigations suggested the effective utilization of indigenous raw materials. This new paint, when compared with the paints used by other maritime nations, may not meet all the demands. Thus the Coal- Tar Epoxy used elsewhere may have better qualities, but the fact remains that without resorting to import of such systems, indigenous substitutes have been given to the user. But the vinyl paint suffers from a major drawback. The surface of the ship has to be prepared properly and meticulously. The dockyard therefore needs very stringent regulations for preparing the surface.

6.5 EUREKA

The cry arose for giving a paint which will require less surface preparation for adhesion. The stringent conditions needed for vinyl were beyond the scope of many dockyards. Anew formulation was developed by the laboratory, taking into consideration. The difficulties of the dockyards. The new paint was not based on vinyl the victor, but it was a coal chlorinated rubber resin. The chlorinated rubber resin showed excellent adhesion characteristics.

The new paint developed can be applied on any surface if rust is removed first. The mode of rust removal depends on the choice of the managers and the availability of implements. The rust may thus be removed by simple wire brushing or by chipping the corroded regions. In either case, the paint, when applied, remains on the surface. In fact, the research in this new wonder medium led to the development of thixotropic paint systems. The paints began to use lower viscosity grade resins and other additives.

The new paint scheme opened up new vistas in underwater protection. In this system, one can increase the thickness of a paint coat to increase the resistance of the surface. A high build composition using aluminium pigment has. Also been applied on ships with promising results. Such a heavy duty paint, even though applied in thicker coats still retained the same toughness of the film without any sagging or running off on the vertical surface

The chlorinated rubber based anticorrosion paint is compatible with all conventional and newer generations of antifouling paints. Thus, the battle between man the and the dual forces of barnacles and cancerous corrosion has ended with the victory dance in favour of man. The saga of the flight with the 'enemy without' and the 'enemy within' celebrates the glory of man the crown of Creation.

7. The Knight of the Rust

The glory of knights has been sung by such eminent historian-novelists as Sir Walter Scott. Their heroism is unmatched and bravery beyond comparison. However, one such knight has remained unknown and unsung to most of the populace. This little known warrior, the knight of the rust, has for years been battling against corrosion to protect the beautiful buxom beauties, the ships riding on the crest of ocean.

The knight, the knight of rust, fights a valiant battle in the vast oceans and in deep regions of soil to protect iron from corrosion. The Russian books call a him the 'protector' while unpoetic British call this a battler Cathodic Protection System. The protection offered by this brave battler is universal if the war is fought in zones where water is present. One cannot thus protect cars or railway bridges with cathodic protection, but a ship is most certainly protected when at sea or even outside.

7.1 CHARGE, HE SAID

The most common of the words used by the knights of yore was, Charge! as soon as the enemy was sighted. This famous quote of the knights is the password of the modern-day knight of the rust. The protection offered by this knight against the enemy of corrosion is also by 'charge'. Of course, the charge in this case is an electric charge produced by the protector; this charge combats the corrosive current produced in the battle.

Corrosion is an electrochemical reaction. It takes place in a metal when a conducting medium is present. The medium may be fresh water, sea-water or even moisture present in the soil. Iron, the most widely employed metal, is most susceptible to corrosion.

The iron we see as a single metal in fact contains several impurities. These impurities are not visible but are present in microscopic state and every microscopic impurity gives rise to certain electrical charges and releases electrons. The nearby area of the metal on the contrary receives these electrons. The area of the metal losing electrons is known as anode while the one receiving the electrons is the cathode. The anodic area loses the metal and thus gets corroded. Similar anodic and cathodic regions are produced at several places in the metal since the impurities are distributed throughout. Hypothetically, if iron is produced free from all impurities corrosion will be minimum, but such a situation is impossible in practical life. If the charges produced in iron causes rust, the counter charge of the knight prevents rust

7.2 CALL TO NEPTUNE

Corrosion cells formed on a single metal spread to the entire metal and cause more corrosion, but this is nothing compared to what happens in the case of two different metals joined together and placed in the same electrolyte. To say the least, the results are disastrous. One of the two metals survives at the cost of the other which dissolves completely.

This was learnt by an American millionaire at a eat cost. This American millionaire decided to build an ideal yacht of a metal which will resist corrosion. This was in the forties when the Germans had discovered an alloy known as German silver. This alloy showed excellent properties of corrosion resistance while retaining the silvery shine. The millionaire called the best architects and shipbuilders to build his dream boat which he christened as The Call of the Sea.

The ship was built. The keel and the hull were shining white with no ungainly stains of corrosion. The interior of the yacht. Was befitting the exterior. The decor was lush with thick wall to wall carpet and plush with polished mahogany. The day of launching came. The blocks holding the yacht were removed. A lady broke champagne on the hull. Everyone was waiting with bated breath to watch this beauty sail in water.

But lo! The hull of the yacht disintegrated on the blocks which supported her. The great detective Sherlock Holmes, if asked, would have said "elementary my dear Watson". Although the boat was built of German silver, it was fastened with copper rivets. Inevitable had to happen. Two dissimilar metals were coupled together in the moist sea-water atmosphere; corrosion had to occur and rivets gave way. The yacht, The Call, of the Sea, remained ashore calling aloud to the Roman God of the Sea, Neptune.

7.3 PERISH AND PROTECT

This principle of bimetallic corrosion was used to advantage by the great chemist of early 19th Century, Humphry Davy. In the first place he impressed upon the wooden boat builders that purity of copper should be very high. Then he advised them to use only copper nails to fasten the copper sheath as preventer of fouling. Finally when he found corrosion of copper in the sea, he suggested coupling zinc buttons on the copper sheath. These buttons dissolved so that copper did not corrode.

This is the principle of catholic protection. In catholic protection too, two dissimilar metals are coupled together in the same electrolyte so that one metal dissolves and in the process protects the other . The electrochemists have identified the corroding metal as the less noble than the one receiving protection. Thus the less noble metal perishes in order to protect the more noble metal which may be any like iron, or copper

7.4 ROB PETER TO PAY PAUL

To rob Peter to pay Paul is probably the simplest method of discharging one's debts, although many may disagree with this philosophy. Ironically, metal are the greatest champions of this easy virtue and yet get away with impurity. Chemists are wonderful people. Once they realized that a metal can be protected effectively by sacrificing another, they began to search for the richest to rob.

The primary aim of all the shipbuilders was to protect the iron hull. Thus iron is the nobler metal, so the other metals investigated must be less noble. They must possess the ability to protect the noble iron. The first task was to study the corrosion potential of each metal. Corrosion potential of metals however is an arbitrary term. It has to be described with reference to an electrode. Thus corrosion potential may be determined with respect to reference electrodes which may be silver chloride electrode, saturated calomel electrode or zinc electrode. Although values of the potential may be different the trend remains the same. Three metals which have been used extensively are magnesium, zinc and aluminium for protection of ships hulls. Thus robbing electrons from any of these three metals paid for the protection of iron hulls.

7.5 OTHER SIDE OF ALASKA

The credit for the practical application of the principle of cathodic protection to ships goes neither to Europe nor to the U .S. Europe brought about the renaissance and revival of sciences. England proudly proclaims an imposing list of scientists and inventors. The United States of America has also had her share of scientists and inventors. Yet none of these countries consider the practical aspects of protecting ships through cathodic protection. The credit for this goes to Canada, the commonwealth country on the other side of Alaska.

It is true Sir Humphry Davy showed in 1824 that copper could be protected using zinc anodes. But, the idea was buried once the steam ships with iron hulls replaced the wooden ships. In fact, this principle with vast potential for protection of even iron ships was apparently never considered.

After doing extensive pioneering work in this field of Cathodic Protection, the Canadians began implementing the principles of protection. By, 1954 the Canadian Navy had already protected more than fifty battleships. The principles thus discovered by the scientists in that part of the British were successfully employed by people in a country across the mighty Atlantic Ocean and beyond the mountains ranges of Alaska. Soon, the other countries followed suit. This knight of rust began its memorable journey by protecting the weak and meek ships and boats in major countries.

7.6 THE KNIGHT RIDES TO INDIA

Crossing the cold mountain ranges in Canada, this knight of rust trotted over the mountain ranges of the Himalayas to India. It rode over the waves of three oceans to arrive at Bombay on the shores of the Arabian Sea. The Naval Chemical and Metallurgical Laboratory received the guest with respect and honour due to him.

The problem of underwater corrosion of ship's hull was serious for the naval ship because most of the paints were failing to survive even a short period of nine months of continuous protection. True, an anticorrosive paint was developed and delivered to the Navy. But this was not adequate for two reasons. The ship in a dry dock is rested on wooden blocks so that the area of keel is virtually inaccessible for effective protection with the paint. Secondly. the paint is only a physical barrier between the ocean environment and the active surface of the metal. Hence, this barrier must be total. The surface preparation such as shot blasting before the application of the anticorrosive paint is never perfect. As a result, the paint, though uniformly applied, leaves areas at micro levels where earlier corrosion products have remained. At such points the paint film deteriorates faster and corrosion is excessive. Anticorrosive paint is thus effective but to a limited extent since it leaves out surfaces which are excessively prone to corrosion.

The laboratory, after investigation decided that cathodic protection of ships, in addition to application of anticorrosive paints, is the only answer to the problem. Research in the material for cathodic protection for Indian ships began by evaluating the performance of the three suitable materials. Thus the performances of magnesium, zinc and aluminium anodes were examined. Zinc anodes have been employed by the British Navy and hence these anodes were imported. The anodes bearing the musical name of C-Sentry were fitted on a harbour craft as a first phase of development. Simultaneously, anodes of magnesium and aluminium were investigated extensively in the laboratory.

Magnesium anodes have been cast in India. This was necessary because casting of magnesium anodes requires special attention. Primarily magnesium used for anodes must be very pure and the industries in India did not have the technical capability of purifying commercially available magnesium or even alloying the metal free from iron impurities. Iron hampers the effectiveness of the anode while simultaneously creating undesirable localized corrosion currents within the anode itself. With aluminium, such problems were not there. Aluminium neither requires importing, nor does it require special technology for purification not known to Indian industrialists.

7.7 ALMIGHTY ALUMINIUM

India has very large deposits of bauxite, the ore from which aluminium is extracted. The Indian aluminium industries have the capability of producing 99.9% pure aluminium for naval use. The easy availability of the metal and the necessary facilities for fabrication of desired alloy of aluminium makes it the most attractive material for selection as sacrificial anode in Indian conditions.

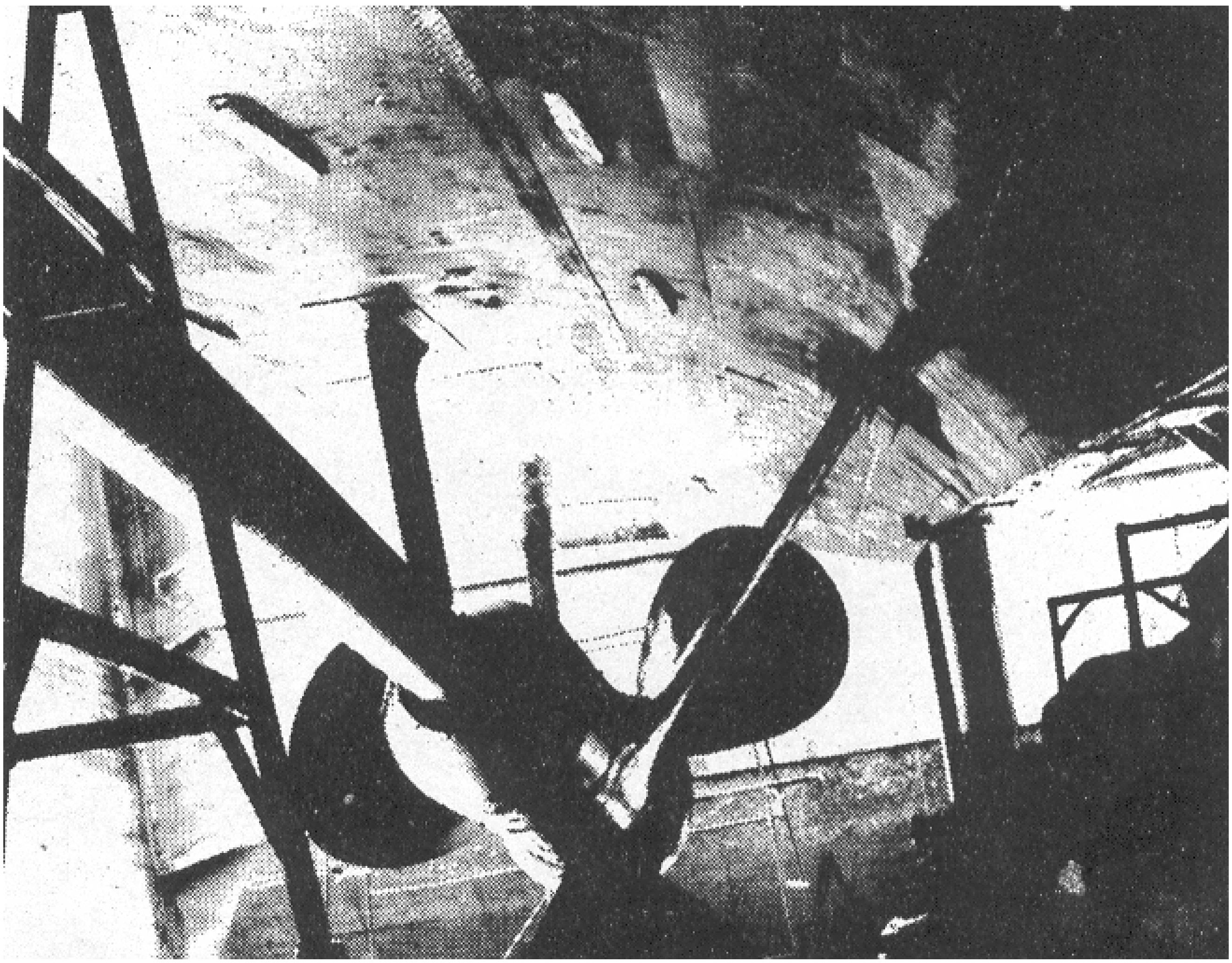
A large number of scaled down anodes were fabricated by the laboratory with the help of Naval Dockyard. The foundry department of the Naval Dockyard rose to the occasion and prepared all the various combination of alloys demanded by the scientists. Thus, the user, Naval Dockyard, and the developer, the laboratory, showed excellent co-operation and co-ordination to combat corrosion. After an extensive evaluation of all the three anodes, it was observed that the composition of aluminium alloy developed at NCML was in no way inferior to the other two, more widely used by foreign countries. In fact, the aluminium alloy had an added advantage of being lighter than the other two. With an average number of sixty anodes required for a medium sized ship (14,000 sq. ft. area) reduction in weight is thus A Considerable; resulting in less consumption of precious fuel. The aluminum anodes have therefore been the most widely used material for protecting the ship as well as deep sea structures in India. The almighty aluminum thus protects the powerful navy of the Indian subcontinent.

7.8 POWER FOR PROTECTION

Two metals when coupled together produce a galvanic current. Each metal exhibits a potential difference which can be measured using a standard electrode. In the sea-water, the open circuit potential of steel with respect to silver/silver chloride electrode has been found to be -750 mV, while the protective potential with respect to standard calomel electrode is noted to be -850 mV. It is therefore necessary that atall costs this level of potential be maintained. If the potential shifts to more negative values, the structure is being over-protected at the cost of the anode. Further, the higher densities of current produced during over-protection are likely to produce more alkali ions at the steel cathodes resulting in alkali dissolution of the surface paint.

A shift towards less negative values of the potential indicates less protection to the structure. This leads to ineffective protection and results in corrosion. In protecting the steel structure a current is generated between the anode and the cathode. The amount of current generated determines the protection. Thus, it has been estimated that one square foot of zinc anode will protect 800 square feet of freshly painted surface. But the same anode will protect just about half the surface after one year. This has been computed with reference to vinyl anticorrosive paint and the values will vary with a different painting scheme. The current densities also vary on the state 1 of the structure; under cruising conditions, more current is needed for protection.

The power of protection required for aluminium anode has been calculated to vary from one to four milli amperes for every square foot area. Thus for a medium sized ship at rest and anchored in the harbour! a current density of 35-40 A will be needed to protect. I an underwater area of 14,000 square feet. Atypical medium sized ship thus required 52 aluminium anodes, each weighing 10.5 kg. This gave a protection to the ship for as long as two years and seven months. The weight for zinc and magnesium anodes, on the other hand, was 25.0 kg which undoubtedly added to the tonnage of the ship.



The anode material dissolves while protecting the cathode. The values of the consumption of the anodes were found to be of the order of 65 kg for every 1000 sq. ft. for both magnesium and zinc anodes while it was a mere 20 kg for 1000 sq. ft. for aluminium. The laboratory by 1972 had protected a total 4,91,610 sq. ft. of underwater area of the naval ships. The power of protection given by the knight of rust, gave excellent Striking power to the strike force of the fighting armada of the Indian Navy.

7.9 PANCHAYANTRA FOR PROTECTION

Panchatantra, the embodiment of famous five principles of diplomacy, was narrated to the sons of a king by Pandit Vishnu Sharma. This enabled them to live free from problems. The Panchayantra, on the other hand, signifies five instruments or mechanisms by which the problem of corrosion could be combated effectively. Panchayantra of protection is collectively known as the Impressed Current Cathodic Protection System. This is the climax in the development in the cathodic protection system of ships and underwater structures. The protection offered by the system ranges from anywhere between fifteen to twenty years of active sailing life.

The sacrificial or galvanic anode system described earlier led to the detection of a few elementary principles of catholic protection. During the operation, a self-generating current is produced between an anode and cathode. It may be regarded as the simplest form of battery cell operating in sea-water. The energy here is not stored for driving automobiles or trucks, but is used in giving protection to the steel hull of a ship. This protection is given by impressing a current of the order of 15-35 mA/m^2 of painted hull.

However, as is the case in every battery system, the anode dissolves in the process. Once the anode is consumed the protection to the structure is stopped and the corrosion process is reactivated. A ship must then be brought to dry dock for the fitment of new anodes. There is a recurring expenditure on the renewal of anodes. Further, the current impressed upon the anodes depends upon the material of anode and is not under the control of any human agencies. The increase in tonnage by the fitting of such anodes not only increases the frictional drag of the ship but also increases the noise level which is undesirable in a fighting ship. The vision of the naval architect in designing a beautiful streamlined ship is shattered by the ungainly sacrificial anodes made of magnesium, zinc or aluminium.

These deficiencies led to the development of a new type of cathodic protection system, where current at the cathode is artificially impressed at the required level. The anode is made of inert materials, like platinum, which do not get consumed while protecting. Other countries have experimented with platinized titanium also. But both these have to be imported and are cost prohibitive.

The Naval Chemical and Metallurgical Laboratory has always tried to utilize materials within the easy reach of the country .Intensive evaluations have shown that an alloy of lead, silver and antimony gives a performance equal to what platinum has &given elsewhere. Once again silver, like aluminium, is also quite freely available in the country and hence the problem of short supply of material at critical periods would not arise. The laboratory investigations were translated into designs necessary for the protection of ship. The entire Impressed Current Cathodic Protection (ICCP) system developed here revolves around five instruments or yantras which form the Panchayantra of protection. These five components of the system have been briefly described and, needless to say, the absence of anyone of them makes the system inoperative

(i) Yantra for Yatra

This is the first and the foremost condition where-the vehicle of yatra, namely the ship itself forms the cathode of the system. The hull of the ship shows different potentials with respect to various electrodes. A silver/silver chloride electrode shows a -800 m V protective potential whereas a zinc electrode may show +250 mV. The corroding potential for the two electrodes is-600 mV and +450 mV respectively. The current required to achieve the protective potential is calculated to be 15-35 mNm2of a ship painted with a good anticorrosive paint. Thus, a current ranging from 15-35 mNm2 will be needed to be impressed upon this yantra of yatra, the ship, for effective protection

(ii) Yantra for Rabha

The rakshsk or the processor against corrosion IS Me newly developed lead-silver-antimony anode. Unlike in the cathod. Protection system, the number of these inert anodes is considerably fewer. A vessel of moderate size needs hardly two anodes as compared to 52 sacrificial aluminium anodes. The new anodes weigh only 20 kg each and can be placed either protruding from the hull or recessed flush with the metal. Thus the ship will not have to drag its feet (keel) since, although it is leaded, it is not weighted.

This yantra for raksha, however, will draw large current of the values varying between 35-40 A and hence it would be vital to insulate it effectively from the metal of the ship. This is achieved by protecting the region adjoining the anodes by a dielectric shield of fibre glass. Our knight of rust now is not only armed but is also well armoured.

(iii) The Madhyama

Like that great warrior, Bhima who occupied central place among the Pandavas, this yantra of Sandarbha: or the Madhyama occupies the central place in the ship. This is the reference electrode of the system and must be kept always at the mid-ship region where at r almost every time water is available for conducting the charge. The function of the reference electrode is to measure, monitor and regulate the hull potential.

Almost all the countries in the world have used “silver/silver chloride electrode as the reference electrode. It is delicate in structure and is therefore more susceptible to damage. After extensive evaluations, the laboratory replaced the silver/silver chloride electrode with zinc electrode. The zinc reference electrode has been made of high purity zinc and compared to the delicate electrodes used by , others, it is quite sturdy like Brim and can withstand the rough handling. The Madhyama or the reference electrode is the heart of the entire system

(iv) Yantra for Shakti

In the sacrificial anode type of system, once the anode and cathode are in electrical contact, current is automatically generated. But not so in the new system. Here shakti or power for the system has to be given by an external source. The power needed to operate the ICCP system is direct current and not the alternating current normally available in the hull. As a result this D.C. supply is obtained from batteries or by converting A.C. to D.C. Once all the fitments of anode, cathode and reference electrode are completed and the units are properly connected to each other and to the power supply unit, current starts flowing from the unit. A high current is needed for protection of ship both at the hull and at the propellers and this has to be provided by this power supply unit. The shakti from this power supply unit must be continuous to provide the necessary current and should also be sturdy enough to last the extended periods of service. The Yantra for Shakti is thus the driving force of the new Impressed Current Cathodic Protection System.

(v) Yantra for Niyantrana

Niyantrana or control of the protective potential is the primary target of the new ICCP system. The final stage of the cathodic protection system is to regulate the power to the cathode. The zinc reference electrode gives the feedback data on the potentials existing on the hull and it is the responsibility of the control unit to regulate the power supply from the source. The excess of current will produce over voltages resulting in the electrolysis of sea-water and liberation of chlorine which are detrimental to the anode. The under protection of the hull, on the contrary, may result in creating corrosive atmosphere. It is the job of this Yantra for Niyantrana to control the current fed to anodes. This control unit designed by NCML can be operated automatically or manually. The auto control unit is so located that the personnel on the ship have an immediate knowledge of what is happening below water

The Impressed Current Cathodic Protection System encompassing the Panchayantras has been fitted on several naval ships. It is more than ten years now since the first unit was installed and so far the system is going strong.

The knight of the rust continues to protect the meek and the weak. The 'damsels' plying on the vast coastline of India are no more in distress. The valours of this knight are known more by the effect than by his appearance. He lies beneath the ship's hull where neither you nor I can see him while the ship is sailing. Let this knight ride underwater as this way he protects the 'lady' from the cancer of metal, the corrosion or rust.

8. War Losses

Till the advent of ships made of steel, the wooden boats were the primary target of destruction.
Columbus had to abandon one of his voyages mid way because the wooden hulls of his fleet were eaten away by this enemy. No estimate of his losses is available to modern historians, but the fact remains that he had to organize his resources again to discover America. Loss of time and resources to this most optimistic explorer must have been enormous.

A bridge in San Francisco in the U.S.A. collapsed one fine morning in the early twentieth century .The cause was again the menace marine battler. The bridge had to be rebuilt but the cost of the destruction was never worked out. Such cases of unrecorded destruction by this foe of fighting crafts may be very large but one has to look up recent history since the destructive role of these marine battlers is recognised only now.

The first and foremost effect of barnacles on the battleship is the increase in fuel consumption. The reasons could be many ranging from increased friction, to increase in tonnage of the ship. The increase in the fuel consumption naturally leads to increased fuel bill for the shipping companies. The figure for this increased fuel cost has been worked out by NCML to be Rs. 250 crores per year.

The second cost effective parameter is the dry docking of ships at frequent intervals for fresh antifouling protection. Calculating the cost of dry docking at the rate of a modest seven lakh rupees, the Indian Navy alone has to spend about one crore rupees for the naval fleet on an average every year. The bulk of the cost of dry docking is attributed to the labour force required to remove the barnacle debris from the underside.

Western countries have realised the damage due to the fouling done to their vital power stations, either conventional or nuclear. However, such a realisation at home is yet to come in full way. The power plant set up near Madras, however had the' foresight to consult NCML regarding the methods of combating the enemy. The laboratory after intensive evaluation both under static and dynamic sea-water conditions tested the use of biocides effective in preventing settlement of organisms. The schedule of treatment drawn by the laboratory has so far prevented the barnacle forces gaining an upper hand. The plant has been operating for seven years now in waters heavily infested by the artillery forces of MBT (mussels, barnacles and tubeworms).

The battling barnacles and the allied force of cancerous corrosion jointly have brought enormous losses to different nations. In several areas, where the support of barnacle forces was not available, the rust fought relentlessly and single handedly. The marine corrosion of metals has been extensively monitored and the losses computed. It has been officially declared that an annual loss of Rs. 1500 crores is incurred by the country due to marine corrosion every year.

The losses incurred by the industrialised countries like the U.S.A. and Japan are of the order of 6,000 million and 92 billion U.S. dollars respectively. The figure for Australia is a modest 470 million U.S. dollars and that for U.K. 600 million pounds. The U .S.S.R. pays an enormous amount of six billion roubles towards the cost of combating corrosion.

Compared to these industrialized countries, India spends a mere 4000 crore rupees on resisting the rust. Of this, marine corrosion itself accounts for a sumptuous share. If corrosion is costly, the protective technology is not in any way less. The problem of underwater corrosion has been effectively controlled by the Impressed Current Cathodic Protection Systems. Thus, the average cost of corrosion protection for each ship is just about ten to twenty thousand rupees a year.

Antifouling paint technologies, however, cannot claim to such achievements. Even after increasing the dry dock interval of the ships, the cost of protective technology still remains prohibitive, a major share of the expense being spent on deployment of manpower. The research is continuing and new concepts are being worked out at fast pace. Unless a protective system proves to be effective on a long-term basis like the anticorrosion technology, the barnacles will continue to sap the nation of its vital resources.

The wars fought with the forces of that fearsome, the barnacles, have been won in limited area. However, due to their astronomical number and adaptive techniques, they have overall superiority over the technologies developed by man. Man, probably has met his match in this enemy, who improvises its attack even before the brain of man can register it. It has been a war lasting centuries, and it appears that the fight will continue even into the twenty-first century and beyond.

The corrosion prevention technology which has shown success for ship has still to provide effective protection to other industries. Year in and year out, corrosion causes severe failures for which better prevention technologies are wanting. As on date, corrosion is at best controlled by using effective preventive measures, which, however, may not prove effective once corrosion sets in. Like cancer, corrosion also has no effective treatment except s~rgery of the infected region. The scientists working for protective technologies either in India or elsewhere, have found their efforts always yielding less than perfect results.

Rust Fight We Must

Mighty ships upon the oceans
    Suffer from severe corrosion;
Even those that stay at dockside
    Are rapidly becoming oxide.
Alas ! that piling in the sea
    is mostly Fe_2O_3
And when ocean meets the shore
    You will find there is Fe_3O_4,
Cause, when the wind is salt and gusty
    Things are getting awfully rusty.
We can measure, we can test it;
    We can halt it or arrest it;
We can gather it and weigh it;
    We can coat it, we can spray it;
We can examine and dissect it;
    We cathodically protect it.
We can pick it up and drop it,
    But heaven knows, we never stop it.
So here's to rust: No doubt about it,
    Most of us would starve without it.

(By Watson, T.R.B., Sea Horse Institute, Wrightsville Beach, N.C., U.S.A. Published in *Materials Performance*, June, 1974).

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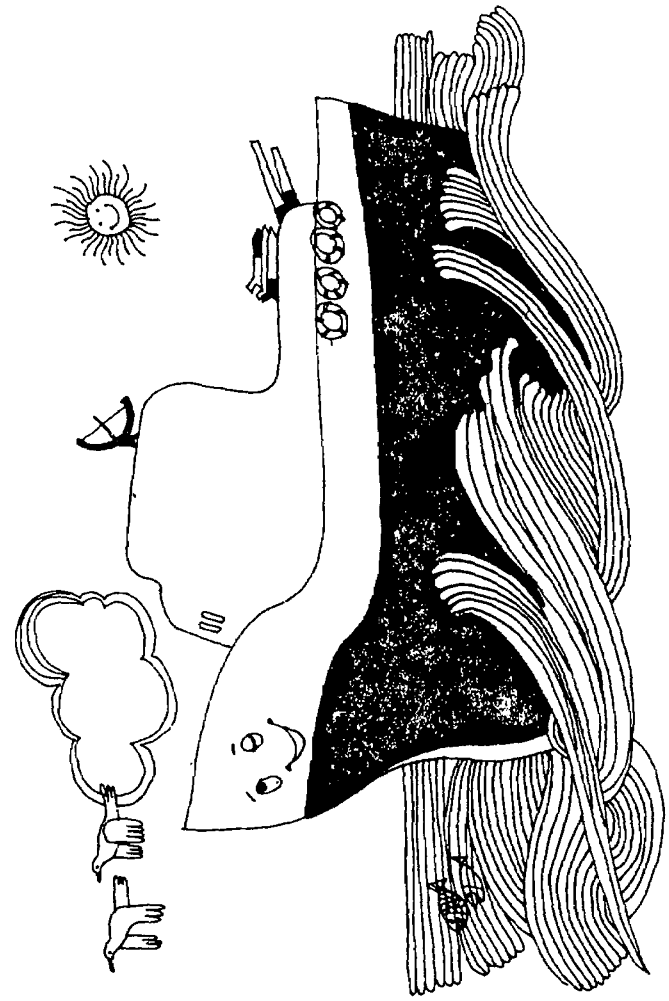

Glossary

Algae	: General name for aquatic plants of lower order containing chlorophyll
Antennule	: The foremost appendage of the mouth part of larva by which it seeks out suitable substrate for settlement
Armada	: Fleet of warships
Bacteria	: Extremely small, relatively simple micro-organisms traditionally classified with fungi. Many bacteria are known to produce diseases
Barnacles	: Common name for a number of species of crustaceans. They have jointed appendages and are akin to prawns and lobsters
Biotic succession	: Order of settlement of animals and plants of different groups
Bryozoans	: Aquatic invertebrate animals without well-defined cell structure. Always occur in colonies

Byssal threads	:	Fine threads produced by brivalve mussels with which they adhere firmly to a surface
Calcareous	:	Organisms with deposition of calcium carbonate
Cypris	:	The free running larval stage in the development of barnacles after which the next stage is the adult
Diatoms	:	Unicellular algae
Detritus	:	Suspended sand and organic material settling on a surface
Dry dock	:	A dock providing support for a vessel and a means for removal of water so that the bottom of the vessel can be exposed for repair, painting
Encrusting	:	Forming crusts on the surface
Flotilla	:	Small fleet
Heterotroph	:	An organism that obtains nourishment by breakdown of organic matter
Hydroid	:	Organisms belonging to phylum coenlenterata usually found in colonies
Inflorescence	:	A flower cluster; collective flower of plant
Jelly fish	:	Also belongs to coelenterata but

		has a large float for the colony by which it moves in water. A dreaded form is the Portugese man-of-war
Keel	:	Main timber of a boat or a ship running the entire length of its bottom
Mussels	:	Shelled marine organisms many of which are edible. Belong to the division Mollusca of animal kingdom. Other members are snails, slugs, octopuses, oysters and clams
Operculum	:	A flap or lid closing the aperture in barnacles through which the mouth part of animals take in water
Oyster	:	Edible bivalve mollusc like clams
Protozoans	:	Single-celled invertebrate animals
Sea anemones	:	Marine coelenterate with well-defined mouth and alimentary system
Sonar	:	A system that uses under-water sound at sonic or ultrasonic frequencies to detect and locate objects in the sea or for communication. Derived from SOund Navigation And Ranging

Stolonoid	:	A group of erect bryozoans that spread by means of stolons, elongated projections in the body wall
Tentacles	:	A slender fleshy growth on the head or about the mouth of many animals, used for holding food and prey
Teredo	:	A distant cousin of marine mussel which lives on wood and timber. The body is worm-like and hence called teredid worm
Tubeworm	:	Fellow animal of the group Annelida to which earthworm belongs
Tunicates	:	Also known as Ascidians. The first Chordata from which higher vertebrate forms including men are believed to have evolved.