CHAPTER 1

INTRODUCTION

In the middle of the 19th century, antifouling paints were developed to prevent marine growth on ship hulls. Due to fouling, there was an increase in fuel consumption, reduction in vessel’s speed, increase in greenhouse gases, accelerated corrosion and propagation of invasive species.

1.1 BIOFOULING

Fouling is the growth and accumulation of marine organisms on vessels and other movable marine structures which affect their performance and can lead to spread of invasive species.

1.1.1 Mechanism of Biofouling

There are two stages of fouling. Microfouling refers to a layer of microscopic organisms including bacteria, diatoms and the slimy substances they produce. It’s a two-step process where primary and secondary colonization (Abarzua et. al., 1995) takes place. Bacteria and diatoms are the primary colonizers. They get adsorbed near the surface by Brownian motion, electrostatic interaction, gravity and vander Waal forces. Since at this stage they can be easily removed, the phenomenon is termed reversible. When these primary colonizers adhere to the surface by using extracellular polysaccharides (consisting of mostly glucose and fructose) produced by them, the attachment becomes irreversible (Abarzua et. al., 1995) forming primary film. Secondary colonizers consist of spores of macroalgae and protozoa which appear soon after development of primary film.

Macrofouling (5th stage shown in Fig. 1.1) refers to large, distinct multicellular organisms visible to the human eye, such as barnacles, tubeworms, mussels, fronds of algae and other large attached or mobile organisms. Their larvae are called tertiary colonizers.
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Fig. 1.1  Steps of biofilm formation

The development of fouling organisms has also been considered in five stages (Compere et.al., 2001). In the first stage, immediately after the structure is immersed, primary film is formed due to adsorption of organic and inorganic macromolecules (Baier, 1972; Compere et al., 2001). In the second stage, bacterial immobilization takes place on the surface. In the third stage, bacterias create extracellular polysaccharides and by adhesion attach themselves forming microbial film on the surface (Abarzua et.al., 1995). The fourth stage corresponds to development of a complex community with the presence of spores of macro-algae, protozoa on the surface and the last stage is attachment of larger marine invertebrates such as barnacles, mussels, macroalgae. (as shown in Fig. 1.1).

1.1.2 Cause of biofouling

The major cause of biofouling is the ease with which biofilms are formed and they are the oldest and most successful form of life recorded on earth, dating back 3.5 billion years (Schopf et.al., 1983). As the structure of ship is very huge which includes areas such as hull, deck, superstructures, fuel tanks, ballast tanks and others, it offers wide range of exposure conditions leading to attachment of marine species resulting in biofouling. Only forms, which have been adapted to tolerate wide fluctuations in environmental conditions such as temperature, water flow and salinity can dominate and adhere to a
specialized structure as a ship. The existence of adhesive exudates (Extracellular Polymeric Substances, EPS) such as polysaccharides, proteins, lipids and nucleic acids and the roughness of irregular microbial colonies help to trap more particles and organisms (Yebra et.al.,2004). The local severity of biofouling depends upon water conditions, geographical location and the operating pattern of the vessel (Yebra et. al., 2004). Temperature is one of the most important parameters. It is widely known that fouling is generally heavier in regions with high water temperatures. A structure like a large ship in itself offers a wide range of exposure conditions which includes areas such as the hull, deck, superstructures, fuel tanks, ballast tanks, and others. In turn, the hull presents different parts with highly specific operating conditions, going from the ship bottom (permanently immersed in sea water) to the boot top area (subject to alternating immersion conditions), splash area (above the water line with the ship fully loaded) and the top sides (which are practically always immersed and exposed to the atmosphere). Certain areas of the vessel such as near the bow, stern etc. experience higher fluid velocity and hence higher polishing rates. This results in premature fouling. Plates 1.2a and 1.2b are the pictures taken from a vessel Cambell Bay (IMO: 9309124, MMSI: 419079700) when it was in dry dock in January 2014. It is a passenger/general cargo ship built in 2011 and currently sailing under the flag of India. Plate 1.2c shows the menace of barnacles even onshore on any rocky structure. The picture was taken in Awas, Maharashtra in May 2015. Plate 1.3 shows biofouling caused due to mussels on a metal plate. This picture was taken in Naval Dockyard, Visakhapatnam in April 2015. Conversely, areas where the flow rates are considerably smaller would experience lesser polishing rates which would result in insufficient amount of biocides being delivered which would again result in premature fouling.
1.2 ECONOMIC RAMIFICATIONS OF BIOFOULING

Balasubramanyan et. al., (1972), addressed the fouling problems faced by the Indian fishing fleet. Fishing vessels operating in the Indian waters are required to dock at least once a year to remove fouling from hulls, propellers and underwater electronic equipment. Barnacles, tubeworms, bryozoans and mussels are the dominant species. Heavy fouling accumulations on trawlers which have an average speed of 7-11 knots are attributed to lengthy periods in ports. Maximum fouling accumulation occurs at the turn of the bilge, below the keel, on the rudder surface, propeller, sea chests and the water line (Coutts et. al., 2003; Coutts et. al., 2004). Types of ship and trade patterns influence...
docking time; bulkers average five days at port compared with just one day for car carriers (Merchants Exchange of Portland, 2005). It has been estimated that the growth of marine fouling organisms cost the shipping industries over $6.5 billion per year (Bhaduray et. al., 2004).

The main consequences of fouling in marine environment are problems associated with marine structures such as pier pilings, oil platform, sea, land –based aquaculture and shipping. (Armstrong et. al., 2000). The nets that form the cages on aquaculture farms are prone to fouling. In addition, the weight of the fouling organisms can sink rafts that are used to suspend nets or lines. Biofilms formed on pier pilings and oil platforms mean that inspections to check structural integrity are difficult. Macrofouling can cause this layer to increase to several centimetres thickness therefore greatly reducing fuel efficiency. In addition, these biofilms encourage corrosion (Dexter et.al., 1993). Reduction in water intake rates also has consequences for power stations where seawater is used to cool the reactors (Sasikumar et.al., 1994). Economics involved in the biofouling problem of power plant has been explained clearly by Drake, 1977 and Chow et.al., 1987. A 5mm Hg condenser back pressure improvement can equal to 0.5% improvement in the turbine heat rate which approximately equal to 3 additional megawatts of generating capacity (Drake, 1977).

Hull fouling is the major factor for carrying of invasive species. Sessile(fixed to a particular structure) species dominate hull fouling.98% of hull samples taken from commercial ship hulls in the North Sea contained non-native species (Gollasch et.al., 2002).It affects the economy by impose of enormous cost to fisheries, agriculture, forestry and human health. Increased frictional drag due to fouling on ship hulls reduces speed by 10% (Townsin, 2003).Gordan et. al., in 1992 reported that when the bio-film is 1 mm thick, this can increase the ship hull friction by 80%, which translates into a 15% loss in speed.
1.3 ENVIRONMENTAL IMPACTS OF BIOFOULING

Tin and Copper has been used as a primary biocide to prevent the establishment of fouling assemblages on ships' hulls, but in the 1980’s it became evident that its continued use was causing tremendous contamination in marine environment. As reported by Bailey et. al.,(1989), due to TBT (Tri butyl tin) contamination, shell deformations and mortalities of Oyster larvae and also imposex, a disorder where male characteristics is developed in female genitalia in the dog-whelk (sea snails) has been observed. Malformations were observed in many other species and hence it was completely banned by IMO in 2008. Copper based antifoulant coatings soon replaced TBT-based coatings. In addition, to improve the effectiveness of Copper, additional biocides also called booster biocides such as Cuprous thiocyanate, Chlorothalonil, Diuron, Dichloro-octyl isothiazolin, Thiram, Zinc oxide, Copper pyrethione, Zineb, Sea-nine 211 and Irgarol.1051 made their way into the field with varying degrees of environmental risks. Even with these new Copper based antifouling paints, growing concerns over water quality and biological impacts from Copper are there. Copper has been shown to be toxic to aquatic organisms, to accumulate in filter feeders, such as mussels and to damage larval stages of aquatic invertebrates and fish species. Dissolved Copper in excess of 3.1 μgl⁻¹, is reported to be toxic to mussels, oysters, sea urchins and crustaceans (Rivera-Duarte et. al., 2005, Carreau et. al., 2005; Damiens et. al., 2006) and it affects phytoplankton communities (Lane, 1980).

In Denmark, mean Copper concentrations of 13 μg l⁻¹ have been observed in the pleasure craft harbour of Marselisborg (Jensen et.al., 1997a). Similar high Copper concentrations were observed in the skerries (small rocky island) of Stockholm (Bard, 1997). These elevated Copper levels have been observed in the proximity of pleasure craft harbours and pleasure craft traffic. High Copper
concentrations were also observed in aquatic plants. Measurements of Copper performed by the French in the Arcachon bay showed an increase in Copper content in oysters (Claisse et al., 1993).

Shipping accounts for 90% of the global trade of goods (ECSA, 2008). Stern (2006) identified that the transport of goods in the year 2000 represented 14% of the total global GHG emissions. This figure is predicted to remain at a constant level until 2050. Of these emissions, shipping represents 10% compared to 12% as a result of air freight operations and 76% of road transport. The importance of using anti-fouling paint in relation to the GHG emission by shipping may be calculated based upon estimations of power penalties. Schultz (2007) estimated that the effect of not using an anti-fouling system on a ship’s hull may increase power requirements for propulsion by up to 70% when compared to an almost fouling free hull. This can be translated into an effect upon the GHG emission enabling an assessment of efficiency penalties incurred by varying levels of hull fouling, which in turn can be related to the relative efficacy of paint.

Alien species on marine environment and native biodiversity create an impact on fisheries, including mariculture, and other natural-resource based industries, with economic disaster for those communities dependent on them (GISP, 2008) as there are changes in resource competition (food, space, spawning areas) resulting in detrimental changes in the tropic web, changes in habitat (water movement restricted, biogenic erosion of shores), limitation of resources (nutrients, light, oxygen); genetic effects on native species (hybridisation, change in gene pool, loss of native genotypes) resulting in drastic reduction of the population size or even extinction of native species.
1.4 PRESENT STATUS OF ANTIFOULING PAINTS

In the middle of the 19th century, antifouling paints were developed to prevent marine growth on ship hulls. In the 5th century BC, historians reported arsenic, sulphur and oil which were used on ship’s hull; the ancient Greeks used tar and wax in the 3rd century BC. From the 13th to 15th century, pitch, oil, resin, and tallow were used to protect ships. In 1625, a mixture of cement, Copper compound and powdered Iron was used as anti fouling paint. In 1670, a paint consisting of tar, resin, and beeswax was used. In 1791, varnish mixed with Iron sulphide and Zinc powder, using Arsenic as antifouling agent. In 1860, Copper sulphate came to be used as antifoulant in a metallic soap composition. In 1863, antifouling paint using Copper oxide and tar was developed. In 1885, an antifouling paint made of lacquer, powdered iron, red lead, persimmon, tannin and other ingredients was developed. A variety of paints were developed using Copper, Arsenic or Mercury as antifoulants. Binder included turpentine oil, naphtha, and benzene. Linseed oil, shellac, tar and various kinds of resin were used as matrix.

As antifouling paints are designed to continuously leach biocides at the paint/seawater interface which were the predominant means of controlling fouling for a vast majority of the vessels, over a period of years in the latter part of the last century, there has been a marked improvement in the effective life of antifouling paints. Ships were docked every 6 to 8 months in the 1920’s by which time they were heavily fouled (Visscher, 1928). The average docking period had extended to 12 months by1960’s (Skerman, 1960).

It was in the 1970’s after the development of Tributyltin (TBT) based self-polishing paints (SPC) that the dry-dock periods have been extended to five years. Tin-based self-polishing antifouling (AF) paints are based on an acrylic polymer (usually Methyl methacrylate) with TBT (or other biocidal) groups chemically bonded onto the backbone by
an ester linkage. Due to environmental concerns and banning the use of organotins, the Tributyl tin is replaced by other biocidal groups, but the principle of action remains the same. The antifouling (AF) mechanism of this copolymer is that on immersion in seawater, the soluble pigment particles dissolve leaving behind the water insoluble the copolymer TBT Methyl acrylate and Methyl methacrylate which due to their hydrophobicity do not permit the penetration of seawater into the paint film (Anderson, 1995). Seawater can, therefore, only fill the pores left behind by the water-soluble pigment. The carboxyl-TBT linkage, however is unstable under even slight alkaline conditions (Sea water is slightly alkaline). This permits a slow, controlled hydrolysis and results in the cleavage of TBT moiety from the backbone polymer. The dissolution of the TBT moiety causes two crucial transformations, which are primarily responsible for the tremendous success of the TBT-SPC coatings. The first is that the glass transition temperature of backbone polymer is increased from about 25°C to approximately 100°C thereby making it brittle. The backbone polymer becomes soluble. The net result of these two changes is that there is tremendous polishing action when the vessel is in movement. In addition there is also renewal of the paint surface under stationary surfaces due to the dissolution of the backbone polymer after the removal of the TBT moiety. These two mechanisms account for the self-polishing effect under both dynamic as well as static conditions. The polishing rate and therefore the biocide delivery at the paint water interface can be controlled by altering the Methyl-methacrylate backbone polymer length. The longer the chain length, the slower is the polishing rate.

However, TBT based paints have been phased out due to environmental concerns and have now been replaced by Tin-free paints. Tin-free antifouling paints although are not as effective as their Tin-based counterparts are generally satisfactory in the control of
fouling as far as routine operation of the vessel is concerned. However, even the best maintained vessels are fouled to the extent of at least five percent of the total surface area. This fouled area, although a small fraction of the entire vessel surface is the primary vector for transmigration of invasive species.

The leaching rate of antifouling paints depends upon factors such as temperature, salinity, pH, speed of water flow, type of primer coating and age of anticorrosive system, dry-film thickness and effect of slime. The extent of polishing action in SPC paints depend primarily on the hydrodynamic forces at the paint-seawater interface. The higher the hydrodynamic forces, the higher are the polishing rates. Conversely, lower hydrodynamic forces at the paint-seawater interface imply lower polishing rates. This implies that at locations where the hydrodynamic forces are high, the polishing rates would be high and this could result in premature depletion of the antifouling coating. Also, when the hydrodynamic forces are low, low polishing action would result and this would lead to insufficient biocide release at the paint-water interface.

1.5 VARIOUS TYPES OF ANTIFOULING PAINTS

In soluble matrix (contact leaching)

Here binder is insoluble in sea water. These paints are resistant to abrasion and rubbing. But the disadvantage of these types of paints are as biocides wear out, paint film is left as a porous skeleton. The release rate of biocide is excessive. The paint has to be removed and recoated. It last for approx. 24 months. A wide variety of commercial high molecular weight polymers can be used (Rascio, 2000, CEPE, 1999). Eg, Chlorinated rubber, Acrylic and Vinyl. The main component is generally acrylic resins, vinyl resins or chlorinated rubber polymers, Copper and Zinc oxides with or without organo-metallic compounds. In soluble matrix is shown in Fig. 1.2.
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Antifouling toxicants

Fig. 1.2  In soluble matrix (Almeida, et. al., 2007)

Soluble matrix (rosin as a binder)

Rosin slowly dissolves in sea water as the coating is immersed in sea water. Rosin is a natural and very compatible resin obtained from the exudation of pine and fir trees (Rascio, 1988). One of the drawback of rosin is low mechanical strength. Rosin cannot prevent sea water from penetrating into the polymer matrix through hydrophobic interactions (Anderson, 1995), so relatively thick (more than 50 m) leached layers are formed (Anderson, 1995) due to the continuous dissolution of the Cuprous oxide pigments. This behaviour under static conditions is enhanced by the possibility of pore blocking by insoluble salts, which influence the release of biocides. It last for approx. 12-18 months. The main components are Colophony, Copper, Arsenic, Zinc, Mercury or Iron oxides. Soluble matrix is shown in Fig. 1.3.

Fig.1.3  Soluble matrix (Almeida, et. al., 2007)
Self-polishing copolymer (SPC)

In 1960s Self-polishing copolymer was introduced. The leaching rate of these paints is controlled because as seawater reacts with the surface layer of the paint, the biocide is released. Once the surface layer is worn off, the reaction to release the biocide begins again with the next layer. In this way, the leaching rate is the same throughout the life of the paint and it became possible for ships to go up to 60 months without repainting. Self-polishing copolymer matrix is shown in Fig. 1.4.

The acrylic nature of coatings provides strength and durability. The drawback is, it increases accumulation and release from sediments. Triorganotin derivatives were extensively used as self-polishing copolymer due to their wide-range activity, causing no galvanic corrosion on aluminium hulls and being colourless (Omae, 2003). As a biocide, especially, TBT needed to be toxic to be effective in killing off the organisms that would attach to the ship's hull. The main problem was its persistence in the marine environment. Work has been underway to replace TBT by Copper or Zinc in order to create the first TBT-free, self-polishing paints. This technology, using copper or zinc as the chemically bound main biocides and only a restricted number of co-biocides, has now been developed and a number of TBT-free SPC paint systems are available. While using biocides to control fouling, there are two key issues. Biocides (types, quantities) and release mechanism. Most of the major marine paint companies market TBT-free SPC systems, the top-of-the-range products including the Intersmooth Ecoloflex 460 series from International Paint, Chugoku's Sea Grandprix 1000, Ameron's ABC#3, Hempel's Globic SP-Eco 819 series, AlphaGen 10/20/50 from Sigma and Sea Quantum Plus from Jotun, the latter exclusively licensed from BASF NOF Coatings Company. All these systems are marketed with effective working lives of up to 60 months but only three TBT-Free SPC technologies have
been commercialised: Copper acrylate (Polymer --- COO --- Cu --- R), Zinc acrylate (Polymer --- COO --- Zn --- R), Silyl acrylate (Polymer --- COO --- Si --- R). The major characteristics of Self polishing Copolymers are

(a) Based on Methyl-methacrylate polymer

(b) Biocide based (primarily Copper)

(c) Requires “booster biocides”(Irgarol 1051, Diuron, Zn pyrithione etc.)

(d) Uniform and predictable polishing rates (typically 2 – 5 µm/month)

(e) Provides hull protection for 3 -5 years

(f) Releases biocides in the aquatic column that kill non-target organisms

(g) Increasing accumulation and release from sediments causing serious environmental problems

(h) Non-uniform polishing rates due to vessel contours causes paint failure in nice areas and thereby increases the risk of transmigration of invasive species

**Fig. 1.4 Self-polishing Copolymer matrix (Almeida, et. al., 2007)**
**Controlled Depletion Polymers (CDP)**

It is mechanically tough and has no polishing characteristics. It has higher volume solids content (55-60%). Here the drawback is film integrity being generally poor and re-blasting is needed after 10 years. Life span of the paint coat is up to 36 months. Main components are Cuprous compound and booster biocides.

**Foul release coatings (non-biocidal)**

The majority of Foul release systems are based on Polydimethylsiloxane (PDMS)/ fluoropolymer backbone polymer which is extremely flexible allowing the polymer chain to readily adapt to the lowest surface energy configuration (Candries et al., 2001). Although the lifespan of silicones, in theory, is unlimited; such coatings come with a high price tag compared to the alternatives. There are a number of products on the market, including the Bioclean series from Chugoku, Hempasil from Hempel, Biox from Kansai and International Paint's Intersleek series. Such paints tend to be specified for smaller ships. These coatings provide an ultra smooth and low friction surface (hence low surface energy). Performance of foul release coatings determined by three properties:

(a) Surface energy which governs the ability of a surface to bond to another surface. Low surface energy will minimize the strength of adhesion of fouling.

(b) Elastic modulus of coatings influences mechanism by which joint between surface and fouling organisms will fail. Minimum adhesion has been found to correlate with lowest value of elastic modulus tested although this did not correspond to lowest surface energy tested.

(c) Thickness of coating can influence whether separation of an organism from surface will be a peel fracture or a shear fracture.
The advantages of these types of coatings are the fouling organisms that attach can be easily removed. They are chemically durable (Callow, 2011). They control fouling on fast and active vessels (>15 knots). No biocides are being used. It is potential fuel saving.

The disadvantages of foul Release coatings are its suitable for high speed and high activity vessels only and very expensive. Application procedure is very difficult. It is easily damaged by abrasion and shear.

**Nano Technology in Paint coatings**

Nano coatings are coatings that are produced by usage of some components at nanoscale to obtain desired properties. Some of these properties that are imparted to the paints by using nanomaterial are as

(a) **Covering power**: Nanoparticles have much greater surface area per unit mass compared to larger particles. Thus, nanostructured coatings can significantly reduce material requirement and cost; improve performance and functionality in large variety of applications.

(b) **Enhanced strength**: In crystalline solids as the size of their structural components decreases, there is much greater interface area within the material; this can greatly enhance mechanical properties.

(c) **Scratch resistance**: Nano-sized inorganic particles have been observed to provide excellent wear and scratch resistance when compared to same material at macro scale.

(d) **Ultraviolet resistance**: The high UV opacity of the nano particles rutile form of titanium dioxide, coupled with its lower photo activity due to an effective coating system, has been shown to be an effective UV protector for acrylic coatings application.
(e) Fire retardant: Nano sized magnesium aluminium layered double hydroxides (nano-LHDs) can improve fire retardency of the coatings.

(f) Anti corrosive property: Because of the greater surface activity of nano particles they can absorb more resins compare to conventional pigment and thus reduce the free space between the pigment and the resin. Thus, nano particles increase the density of coating, reduce the transport path of corrosive species and enhance the protective performance (Mathiazhagan et.al.,2011).

(g) Anti-bacterial effect: Experimental results have shown that the ability of nano-particles to destroy bacteria is more than micro particles which could be useful for coating in galley, sickbay etc. (Justin et.al., 2012).

(h) Anti fouling property: TBT free high performance antifouling that is both self-polishing and self-smoothening based on the use of nanocapsule acrylate technology has been developed. The primary binder copolymer used in GLOBIC NCT consists of nano-size acrylate capsules. These nanocapsules feature a core that consists of a highly reactive acrylate. This is the binder component that is primarily responsible for the self-polishing effect in the coating. This reactive core is protected by a hydrophobic acrylate polymer shell that controls the rate at which sea water penetrates to the core. Besides this, the polymer shell has outstanding capabilities in providing controlled release of powerful antifouling agents. The self-polishing and self-smoothening capabilities offer a low hydrodynamic drag coefficient, which results in a reduction of fuel consumption.

1.6 IMO REGULATIONS

Facts forced the development of national regulations in countries all over the world. International Maritime Organisation (IMO) adopts
Convention on Control of Harmful Anti-fouling Systems on Ships (AFS Convention). This treaty was made in 2001 by IMO. It has been agreed by states to prohibit the use of harmful anti-fouling paints and other anti-fouling systems that contain harmful substances. In particular, the use of the Tributyltin had to be prohibited, since leaching of that chemical from the hulls of ships were causing deformations in oysters and sex changes in whelks. The resolution recommend that Governments adopt measures to eliminate the use of antifouling paint containing TBT on non-aluminium hulled vessels of less than 25 metres in length and eliminate the use of antifouling paints with a leaching rate of more than 4 µ of TBT per day. Most countries prohibit the use of TBT paints on vessels less than 25 metres in length and limit the leaching rates for TBT where it is used on vessels over 25 metres in length. Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species were adopted by the Marine Environment Protection Committee (MEPC) of the International Maritime Organisation (IMO) at its sixty-second session in 2011, in the form of resolution MEPC.207 (62).

1.7 OBJECTIVE

Environmental concerns about long-term effects of leachable antifouling biocides have led to increased interest in the development of environmental friendly alternatives. Research activities are centered on biodegradable toxic compounds, non-toxic adhesion inhibitors, electrochemical systems and cleaning devices. Our objective in the present work is rather limited and can be enumerated as follows:

(a) To study in vitro and in field, the use of natural biocides as a component of antifouling paints to reduce environmental problems due to paint release and at the same time not compromising with paint effectiveness.
(b) Understanding commercial paint effectiveness with respect to paint depletion of Self polishing copolymer antifouling paint under laboratory conditions.

1.8 SCOPE

Keeping in mind the time limitations, paucity of practical field data available from industry and lack of experimental facilities at one location, the scope of the present work can be stated as follows:

(a) To characterise the various constituents of Neem (Azadirachta indica) seed oil and Karanj (Pongamia pinnata) seed oil using different chemical tools to identify active ingredients.

(b) To study the toxicity effects of Azadirachtin (extract from Azadirachta indica) and Karanjin (extract from Pongamia pinnata) against barnacle (Balanus Amphitrite) larvae in laboratory environment.

(c) To investigate bioactive antifouling compositions at two stations in Visakhapatnam harbour.

(d) To measure commercial paint effectiveness with respect to paint depletion of three Self polishing copolymers, TBT free SPC antifouling paint based on Copper acrylate, TBT free SPC antifouling paint based on nano-capsule acrylate and TBT free SPC antifouling paint with Cuprous oxide and organic biocides as active ingredients under laboratory conditions using drum test apparatus.

1.9 ORGANISATION OF THESIS

Chapter-I Contains the “Introduction”.

After introducing the subject of biofouling, antifouling paints, their relevance to ships and their environmental effects, objective of the thesis and scope within which the present work has been carried out have been highlighted.
Chapter-II Discusses the “Literature review”.

The general ship paint composition, anti-fouling coatings and the painting process which forms the background for the present work bringing the work to application environment is highlighted.

Also, Commercial booster biocides and its drawback have been described bringing out the necessity of using natural antifoulant. Identification of potential biocides has been discussed.

Chapter-III Describes “Extraction and toxicity analysis of the bioactives of Azadirachtaindica and Pongamia pinnata”.

Extraction and toxicity analysis of the bioactives of Azadirachtaindica and Pongamia pinnata” have been discussed.

Chapter-IV Describes “Marine exposure of potential biocides Azadirachtaindica and Pongamia pinnata”.

Efficacy of Neem (Azadirachta indica) seed oil bioactive and Karanj (Pongamia pinnata) seed oil bioactive in preventing biofouling formations on metal surfaces in marine environment has been discussed.

Chapter-V Describes “Antifouling painting schemes to minimize fouling”.

It focuses on polishing action in self-polishing copolymer identifying the niche areas of fouling and by conducting experiment in laboratory conditions; extent of paint depletion was measured using three commercial self-polishing antifouling paint.

Chapter-VI “Conclusion”.

The applicability of Karanj and Neem bioactive in antifouling coatings has been highlighted and their use has been discussed.