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Corrosion and underwater hull maintenance

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CORROSION AND UNDERWATER HULL MAINTENANCE

By

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The contents of this paper reflect my personal views and are not necessarily endorsed by the university.

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A B S T R A C T

In this paper, an attempt has been made to develop one course related to the CORROSION AND UNDERWATER HULL MAINTENANCE. This course is based on the phenomena of corrosion which occurs on the plates of the ship hull, and what are the solutions to lower or to reduce that problem.

In order to meet the training needs of fleet and shore personnel, this course is emphasized on the ship's performance regarding the fuel saving on maintaining the hull surface smooth as possible.

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INTRODUCTION

Ships in service are exposed to an extremely severe environment, and of vulnerable surface, the area of the outer hull is subject more than any other to deterioration by corrosion. In addition, the underwater area is subject to fouling by marine growths, and since neither corrosion nor fouling may be completely prevented, careful consideration must be given to both the initial choice of system for the control of these factors and the planning of maintenance, to reduce deterioration of the hull to a minimum.

Area below water level of the hull is in continuous contact with an extremely well aerated electrolyte "SEA WATER", and is therefore vulnerable.

The boot-topping area is exposed to the above condition when the ship is in the fully loaded state, but it is also exposed to intermittent wetting and drying when the ship is more lightly loaded, both combinations give an extremely arduous environment. This area is the most vulnerable of the outer hull, by the nature of the environment, and also, in the case of the sides of the ship, to accidental damage which can occur in the port during tug boats maneuvering or along the concrete of the quay. It is also exposed to damage by fouling organisms.

Topside area, although never completely immersed, is exposed to wind and salt spray, and to ultra-violet radiation from sunlight, all of which encourage the breakdown of the protective coatings and the corrosion of the steel.

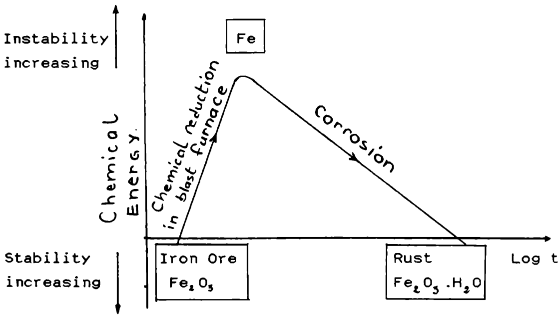
CHAPTER ONE
PROBLEMS

I-1 CORROSION :

I-1.1 DEFINITION :

Corrosion is the chemical reaction of a metal with a non-metal in the surrounding environment, with the formation of compounds which are referred to as corrosion products.

The degree to which this occurs will depend on the rate of the corrosion reaction, which determines the life of the conversion of the metal into corrosion products after a given period of time.



Energy changes in the reduction of oxides to metal and the reverse corrosion reaction.
(Marine and offshore corrosion, K A Chandler.)

Corrosion may be defined as an unintentional attack on a material through reaction with a surrounding medium. the term can refer to a process or to the damage caused by such a process.

Most metals occur in nature in the chemically combined state and energy must be supplied to win them from their ores. Furthermore, once extracted and exposed to natural environments, these same metals attempt to return the metal into the chemically combined state; this is called CORROSION. It is estimated that the annual costs for metallic corrosion, including measures for protection against corrosion, amount to 2000-3000 US$ per inhabitant in the most highly industrialized countries of the world. These direct or primary corrosion costs, may account for anti-corrosive painting or other protection methods, the exchange of corroded equipment which for other reasons could have been used longer, the use of expensive metals instead of carbon steel.

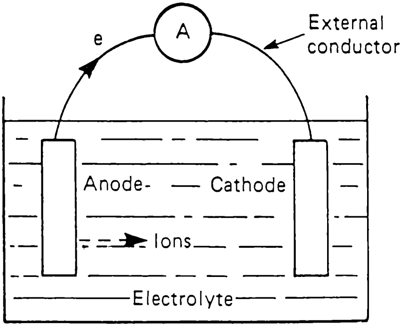
In addition, indirect or secondary costs are involved, for example, as a result of shut-downs in industries due to the corroded apparatus, destruction of large constructions due to the corrosion of small details, or damage caused by leakage of water or oil from corroded tubes and containers.

Beyond an economic evaluation personal injuries and health hazards are often caused by corrosion.

I-1.2 MECHANISM OF MARINE CORROSION :

Corrosion that occurs in sea water at ordinary temperatures is electrochemical. It basically consists of two electrodes immersed in an electrolyte (liquid that conducts electricity) and joined by an external conductor (electric wire).

The anode is the electrode from which positive electric current flows to the solution or where electrons flow through the external circuit in the reverse direction; the cathode is the electrode which receives a positive current from the solution or where electrons flow in the reverse direction. During this process the electrons liberated by the oxidation reaction at the anode are transferred through the external circuit to the cathode where they are accepted by species in solution, which is simultaneously reduced to a lower state of valence.

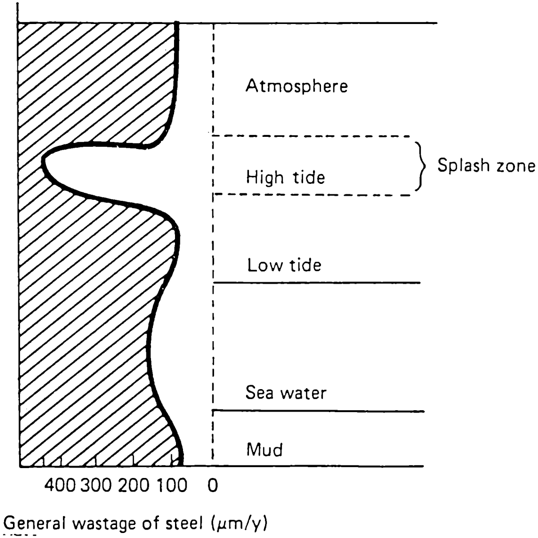


Simple electrochemical cell

I-1.3 MARINE ENVIRONMENT EFFECTS ON CORROSION :

Sea water covers two-third of the Earth's surface and is an environment that the ships have always had to withstand, as have the constructional materials used for harbors between which they ply. Consequently, the corrosive marine environment has always been an important factor to maritime transport, not only the sea water itself but also the air above it which contains chloride from the sea spray. The importance of the marine environment has, however, increased considerably in the last few decades because of the exploration for natural resources in the sea and a realization that the sea can provide energy from its wave motion and fresh water for the areas of the world where this is in short supply. Marine environments are more aggressive than most inland environments and some understanding of their nature is essential if the best use is to be made of the materials exposed to them. Corrosion of many alloys will often be greater on the parts that are not actually immersed in the sea. Figure ( ) indicates the range of different environments covered by the term "marine environment", with an indication of the variations in the corrosion rate of steel that occurs in the different zones.

The most important zone is the sea itself, because it is the chemical nature of the sea water that influences corrosion in marine atmospheres. Sea water contains chlorides which give it the high salinity, a main characteristic. There are, however, other important factors to be considered in relation to the chemical make-up of sea water.


Atmosphere
Splash zone
High tide
Low tide
Sea water
Mud
400 300 200 100 0
General wastage of steel (μm/y)

I-1.3.1 SEA WATER:

The most characteristic feature of sea water is its high salt content. The salt content of the waters of the open sea, away from inshore influences such as melting ice, fresh-water rivers and areas of high evaporation, is remarkably constant and is rarely outside the range of 33-38 parts per thousand. The common average value used for open ocean water is 35 parts per thousand. This is its salinity and is usually expressed as S‰, a convention which approximates the weight in grams of dry salts contained in 1000 g of the sea water. There are two definitions to express the concentration of salts in sea water CHLORINITY and SALINITY. These are related by an empirical relationship established by the INTERNATIONAL COUNCIL FOR THE EXPLOITATION OF THE SEA (ICES):

$$\text{Salinity} = 0.03 + 1.805 \times \text{Chlorinity}.$$

(Marine and offshore corrosion, K A Chandler)

In this case, the chlorinity of the sea is within the range of 18-20.

I-1.3.2 TEMPERATURE :

The temperature of the surface waters of the oceans tends to vary directly with the latitude, and the range is from about -2 oC at the poles to 35 oC at the equator.

The temperature at any location is subject to seasonal variations, winds and currents. The surface of the sea is also affected by the weather but always to a lesser degree than any land mass. In the tropics the annual variations are smaller than those in the temperate zones where they amount to around 10 oC.

I-1.3.3 SPEED SHIP :

Ship speed influences the corrosion rate of hulls in a number of ways. It can results in increase in the amount of oxygen that reaches the metal surfaces, to the removal of protective coatings and may cause the formation of differential aeration cells. Generally, metals corrode at greater rates with increased ship velocity.

I-1.3.4 DISSOLVED GASES :

Dissolved gases can be important in determining corrosion rates in sea water. The presence or absence of dissolved oxygen is a very important factor in the corrosion of metals immersed in the sea. The concentration of the dissolved oxygen is a function of temperature, degree of movement of the water and the length of time in contact with the atmosphere.

I-1.3.5 HYDROGEN SULPHIDE :

Sea water often contains hydrogen sulphide (H_2S) produced by the metabolism of the sulphate reducing bacteria. In summer months, there is a rise in concentration of the order of 30-35 ppm. H_2S is very active in accelerating the corrosion of most alloys.

I-1.3.6 CARBON DIOXIDE:

The progress of corrosion of metals in sea water is often controlled by the presence of carbonate scales.

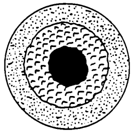
Thus, the amount of carbon dioxide (CO_2) in sea water may have a direct influence on corrosion as well as upon the alkalinity of the sample.

I-1.3.7 CALCAREOUS SCALES :

Sea water contains mainly sodium chloride, it also always contains significant amounts of calcium bicarbonate and magnesium sulphate. These compounds can be of importance in the corrosion reaction where they may act as cathodic inhibitors.

Salt-water Corrosion of Steel

Corrosion in a salt-water droplet on steel just after the droplet has been attached

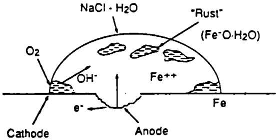


Corrosion in the droplet after the oxygen has been consumed

RED (cathodic)

BROWN (rust)

BLUE (anodic/corrosion)



Cross-section of a salt-water droplet; the supply of oxygen is indicated

I-1.3.8 ELECTRICAL CONDUCTIVITY :

The conductivity of sea water is a factor in determining the amount of corrosion that occurs under immersed conditions, particularly galvanic couples and at local situations (e.g. crevices)

type of water	resistivity (Ω/cm)
pure water	20.000.000
distilled water	500.000
rain water	20.000
tap water	1-5.000
river water	200
coastal sea water	30
open sea water	20-25

I-1.3.9 pH OF SEA WATER :

Sea water is normally alkaline and the pH of the surface layers of the ocean lies between 8.1 and 8.3. The presence of large quantities of hydrogen sulphide tends to lower the pH value (acid), while if there are considerable plants, higher pH value will be found (alkaline). The pH of sea water is also altered by variations in temperature.

I-2 FOULING :

I-2.1 Definition :

Fouling is a term to describe the growth of marine plants and animals on ship's hulls and all structures in the sea. Animals such as barnacles can flourish on smooth surfaces, making them rough. for example, one could compare the surface of a clean ship's hull to a smooth piece of paper, and that of a fouled ship's hull to a piece of sand paper.

I-2.2 Classification :

The fouling organisms can be grouped under microorganisms and macroorganisms. The microorganisms composing the "Slime"-layer are: bacteria, fungi, protozoa and the unicellular algae (diatoms) of which bacteria and diatoms are important groups. The macroorganisms are composed of algae and animals. The most dominating are red, brown and green algae. Among the animals the prevalent shipfouling groups are barnacles, tubeworms, bryozoa which have hard shell and hydroids and tunicates present in soft form.

I-2.3 Development process of fouling :

The development of fouling on a painted steel surface immersed in sea water follows a broad general sequence. First, the surface becomes covered with a layer of slime composed of bacteria and diatoms. Weeds then grow from spores that have become entrapped in the slime. The most usual weeds on ships are green and brown algae. Finally, and often concurrently with the second stage of fouling, animal larvae become attached. Weeds occur only on the sides of the ships in the sunlight areas, green species occupy the upper reaches near the waterline, and brown weeds, the lower areas. Animals occupy mainly the hull's bottom because of the competition of the weeds on the sides.

The important factors increasing the growth of fouling are as follows:

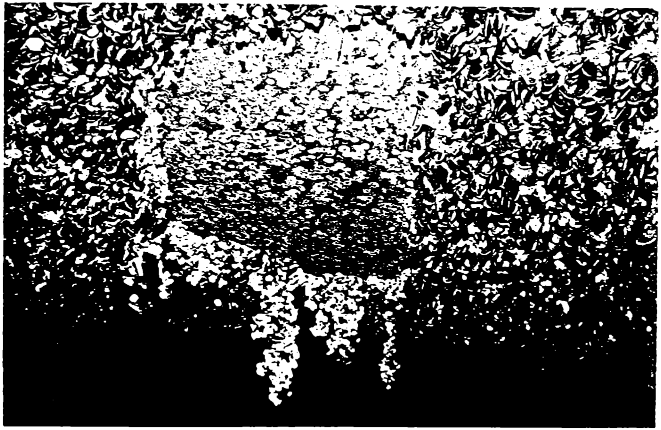
-* Temperature
-* Salinity
-* Ph
-* Oxygen
-* Nutrition
-* Pollution
-* Light intensity
-* Current resistance.

The organisms aforesaid will only settle and survive when the requirements to these factors are fulfilled.

I-2.4 FOULING EFFECT :

The accumulation of fouling organisms can increase the frictional resistance of a ship's hull to passage through the water and can reach significant values. The smallest amount of marine growth, if not removed, can cause increases in fuel consumption by 30 %. From the point of view of hydrodynamic drag on the ship's hull, it is greater than the roughness of the plating by corrosion.

In addition to the increase in frictional resistance incurred by the roughening effect, the shelled animals, if allowed to persist, can cause damage to underlying paint films, by the cutting action of their shells, which results eventually in penetration of the coating. The fouling thus has both a direct and indirect influence on corrosion. Bacteriological activity can have a direct effect, particularly in polluted waters near the coasts or in the harbors. Sulphate reducing bacteria can cause steel to corrode under anaerobic conditions.



Thick fouling such as this must be cleaned by hand-scraper.

CHAPTER TWO
REMEDIES

II- CORROSION COMBAT :

II-1 SURFACE PREPARATION BEFORE PAINTING :

II-1.1 GENERAL :

In marine environments, the corrosion rate is higher, so there is a much greater requirement for high quality protection. This is not, however, achieved just by specifying better coatings. To obtain the standard of protection required involves high standards of preparation of the steel surface and application of the coating to provide the highest quality of dry protective film. This in turn means that specifications must be properly prepared, workmanship must be first class and proper quality control measures are required.

The efficiency of all coatings is influenced by the nature of the surface to which they are applied. It should, however, be emphasized that thorough cleaning of the steel is required for all coatings.

II-1.2 SURFACE CLEANING:

Before the application of various types of protective coatings on the hull surface, it is normally necessary to clean the surface very carefully in order to remove both dirt, such as grease, salts, and oxides, such as mill scale and rust. This preparation is usually carried out in two steps. One step aims at removing organic substances such as oil and grease, whereas the object of the other step is to remove inorganic substances such as mill scale, rust and old paint coats and also to give the surface a suitable finish. These two steps can be repeated several times and in different orders.

II-1.3 APPLIED METHODS :

II-1.3.1 Degreasing : For the removal of oil and/or grease from the surfaces of ships, use can be made of organic solvents or detergents. Solvent degreasing of the surface is usually accomplished by wiping it with rags dipped in a solvent. When using organic solvents, attention should be paid to fire and health hazards. Detergents are usually applied to the surface by brushing or spraying. After a certain period of action mainly determined by paint manufacturers, the detergent is removed, together with emulsified grease and dirt, by brushing with fresh clean water or by high-pressure spraying. A variation of this method is steam cleaning, in which a jet of steam is used to which a detergent is added. The surface is considered clean if a drop of water will spread out in a continuous film. If oil or grease is still present, the water contracts in the form of droplets.

II-1.3.2 Blast- cleaning and abrasives :

II-1.3.2.1 Blast-cleaning : Blast-cleaning is made of the eroding action of a jet of particles (the abrasives) on the surface to be cleaned. Blasting will remove all kinds of impurities, mill scale, rust and old paint coats. The most important types used are:

1/ Nozzle-blasting where the abrasive is propelled against the surface by means of compressed air. For nozzle-blasting in the open air, cheap abrasives can be used which need not be recovered. In hull cleaning, where the nozzle-blasting is used in open air, on the slipway or in dry-dock, for light nozzle-blasting sometimes it is called sweep-blasting or brush-off blasting.

2/ Impeller-blasting where the abrasive is projected against the surface by means of machines provided with impellers wheels. In shipping industry, impeller-blasting can be used for cleaning large areas such as sheet-plates or complicated shapes like profiles.

3/ Vacuum-blasting where the abrasive is propelled against the surface by air pressure, and collected, together with the impurities, by suction. The abrasive is separated from the dust, which is collected in a dust bag, and the abrasive re-used. It is mainly used for special areas such as cleaning welding seams.

On the other hand, wet blast-cleaning method consists of a suspension of sand in water. This solution mixture is propelled against the surface by high pressure pumps. It is mainly used for maintenance work, such as roughening of old paint coats prior to repainting. To prevent rusting from water of bare spots on the hull, inhibitors are added to it.

II-1.3.2.2 Abrasives: The abrasives are small particles which are chosen according to the objectives of the required surface profile. They are determined mainly by particle size or size distribution, hardness, breakdown characteristics and shape. They can be divided into 2 groups: metallic and mineral abrasives. The most widely used metallic abrasives are: cut steel wire, steel or cast iron shot and steel or cast iron grit. The mineral abrasives are cheaper than metallic ores. Currently used mineral abrasives are the following: sand, corundum and some industrial by-products of the ore. Sand has been forbidden by law in most countries because of occupational health risks (SILICOSIS). It is still used in many countries where the safety measures are poor or completly ignored.

II-1.3.3 FLAME-CLEANING: Oxyacetylene flames are passed over the surface to be cleaned; this process is called flame-cleaning. The difference in thermal expansion between the steel surface and mill scale or rust causes the latter to spall off, after which they must be removed by brushing and dusting. Its most important advantage is that it provides a warm and dry surface, this being particularly useful when surface preparation and painting have to be done in humid weather.

II-1.3.4 HYDROBLASTING : A high-pressure water jet reaching sometimes 2000 bar, is projected against the surface through a specially designed, small orifice nozzle. This method is efficient for fouling, poorly adherent paint layers, loose rust and water soluble salts. It has a high consumption rate. Only clean fresh water should be used.

II-1.4 SURFACE CLEANLINESS :

The simplest way to examine surface cleanliness is by direct visual observation with a magnifying lens or a microscope. This involves a qualitative statement of whether the metal is clean from rust and scale or not. Many methods are concerned with the degree of removal of rust and scale by cleaning. It has been standardized in many countries and the most standard methods used to the degree of cleaning are based on the Swedish standard SIS 05 59 00 : 1967 which provides a series of photographic standards and written descriptions of various stages of visual cleanness of steel surfaces after blast-cleaning. It also categorizes the degree of rusting of the steel before blast-cleaning from A to D, the four grades ranging from completely scaled steel to a rusted and pitted surface. There are also other standards using different interpretations of rust, surface cleanliness and even additional sections on welds cleaning. None of these different standards for surface cleanliness can be considered to be completely satisfactory.

II-1.5 SURFACE PROFILE :

When the steel is cleaned with abrasives to remove scale and rust there is an inevitable roughening of the surface. Ideally surface roughness should be considered in three-dimensional terms but there are obvious difficulties in applying such a concept. In practice the profile is considered as two-dimensional. Perpendicular sections of the surface are seen as a succession of peaks and valleys, the so-called "ROUGHNESS PROFILE". Various methods have been used to determine the surface profile of blast-cleaned steel:

* Stylus method: A sapphire or diamond contact point

is drawn over the steel surface and a trace is obtained on a chart.

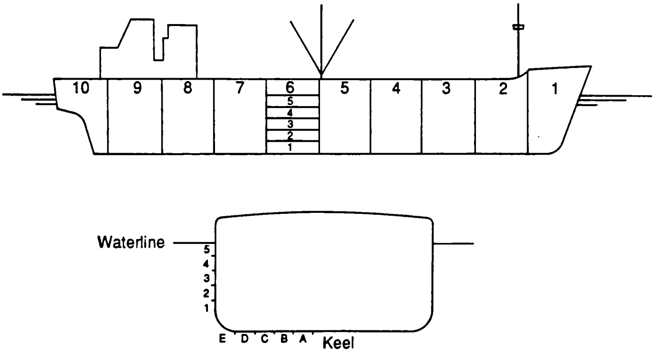
* Microscopic method: It records a profile over a small area by focusing on troughs, then peaks and the differences are measured on the vernier scale.
* Pneumatic method: An air orifice is pressed against the surface and air pressure is passed through it: there is a relationship between the loss of air and the surface roughness.
* Dial gauge: It is fitted to a frame with a fine pointed stylus. Measurements are made on both peaks and troughs. The reading is taken directly on the blast-cleaned surface.
* Comparator method: It is widely used in USA, which consist of comparing blast-cleaned surfaces with prepared standards of known profile height. The comparison is made visually and by touching with fingertips.

Exact determination of the surface profile trace requires skilled personnel and accurate equipment to get a profile trace which can be useful to make a final solution. The profile measurement is important for the effective thickness of paint that covers and protects the steel. Consequently, an empirical relationship between measured profile and paint film thickness has been adopted by most paint manufacturers.

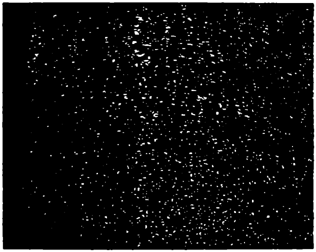
DRY FILM THICKNESS = 3 X SURFACE PROFILE

For some types of paint, manufacturers prescribe a minimum roughness profile for best adhesion.

Measuring Mean Hull Roughness



Blast-cleaning standa



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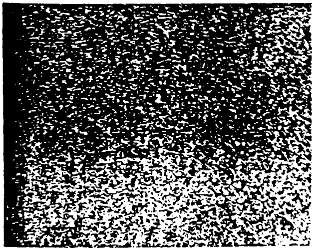
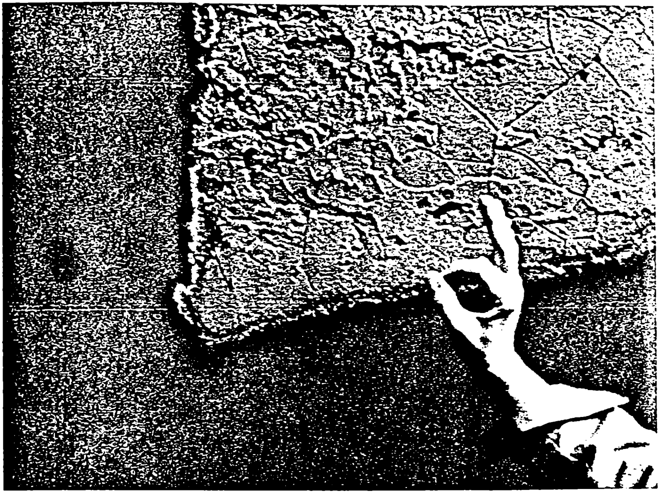


Sa 2 1/2



An eight year old vessel being sandblasted. This reduces the roughness from 450 microns to 150, thus reducing bunkers consumption considerably.

II-2 PAINTS :

II-2.1 GENERAL :

Paint is a coating applied on the substrate, its primary function is protection of the hull against the environment. At the same time, paint is used as decoration, identification, warning, camouflage, image, for ease of cleaning and decontamination.

The protection is made by creating a thin film between the substrate and the environment. The total thickness of the film is, typically, the thickness of ordinary wrapping paper.

The effective life of a protective coating system depends upon a number of factors, few of which have to do with the paint itself. These factors are:

1- The substrate (the hull) and

2- The environment.

Important factors on which the average paint user has little or no influence.

3- Surface preparation; undoubtedly the most important single factor.

4- The quality of the paint.

5- Choice of generic types of paints and their combination into a coating system.

6- Application, not only workmanship and equipment, but also microclimatic conditions during application and while the paint dries and/or cures.

7- Overall thickness of the coating system.

The main objective is to obtain optimum results from the above factors.

II-2.2 CONSTITUENTS :

A paint consists of a medium, also called vehicle, which is the actual liquid part of the paint, some pigments, small insoluble particles dispersed in the medium, plus various additives in minor amounts. The mixing of these ingredients in the right manner and proportion is really what paint production is all about. The many different ingredients are divided into groups according to their function in the paint. The most important constituents of paints are BINDERS, PIGMENTS, EXTENDERS, THINNERS and SOLVENTS.

II-2.2.1 BINDERS :

The binder is that component of paint which, after drying, forms a coherent layer, adhering to the substrate, the pigment particles being distributed more or less uniformly in it. The type of binder to the large extent determines such properties as adhesion, elasticity, gloss and resistance to weathering, water and chemicals. The properties, of course, also depend to some extent on the pigment composition. Many binders for paints are based on bitumens, drying oils, synthetic resins, polymers, or combinations of these. In addition, natural resins or modified natural resins are used to a limited extent in antifouling paints. The choice of binder is in large measure determined by the purpose for which the paint is intended.

II-2.2.2 PIGMENTS :

Pigments are powders which usually are added to paints to provide color, opacity and improve durability. Most pigments are inert but some have inhibitive properties. There are also some pigments having special functions e.g. antifouling, sunshine reflectance and fire retarding.

II-2.2.3 EXTENDERS :

An extender is a white or pale colored powder of limited hiding powder, its function being to impart certain desirable properties to the paint. Thus, the purpose of using extenders may be to stabilize the paint, to prevent it from sagging, to make it matt and to improve its rheological properties.

II-2.2.4 THINNER :

A thinner is a volatile liquid (or mixture of liquids) added to paints to facilitate application by reducing the viscosity. Thinners may be either solvents or dilutents or mixtures of them. They evaporate when the paint dries and they are therefore lost. Their function is a temporary one and they may be regarded as a means of transport.

II-2.2.5 ADDITIVES :

Additives are substances added in small quantities to the paint formulations, their function being to improve certain properties of the paint or facilitate its preparation.

II-2.3 PAINT APPLICATION :

II-2.3.1 General :

A good result of paint application depends on:

- proper planning,
- proper working conditions,
- favorable microclimate conditions,
- correct choice of application method and
- operator skill.

The planning is based on the type on the paint, schedule for monitoring and providing adequate equipment at the necessary time, weather and micro-climate conditions, safety measures and last but not least the experience with similar jobs done before.

The working conditions should be adequate, light, air, ventilation, to ensure the optimum drying of the paint.

The temperature of the area to be treated and the relative humidity of the surrounding air should be taken into consideration to avoid the dew point which can be fatal for the paint.

The application method is generally prescribed by the paint manufacturer according to the type of the coating.

The personnel should be high skilled and well trained when sophisticated equipment is involved. Generally speaking, the equipment is simple to use. Maintenance, which is the most important, should be carried out in adequate time and in the right way, because of the high cost of the materials.

II-2.3.2 Application methods :

The different methods used in painting are:

* Brush which is considered as an old fashioned tool, but still often the most suitable for complex object painting.
* Roller is suitable for treating large flat surfaces which for some reason cannot be sprayed. Painting by roller is about five times as fast as by brush.
* Air spray has been used quite a lot in shipbuilding. The application system is based on the paint being atomized by air pressure and then deposited on the surface to be treated.

* Airless spray is the most widely used method nowadays in painting on large surfaces because of the rapid application. The principle is based on compressing paint to a pressure of between 100 and 450 bar and releasing it in the nozzle of the gun in fine droplets with high velocity. It has shown with that method that dilution of paint can be avoided and good results for thicker paint can be achieved.

II-2.3.3 Application rates :

Based on experience, the table below gives a broad indication of the areas which can be covered by a satisfactory operator within one working hour.

Method applied	Area covered (square meters/hour)
Brush	6 - 10
Roller	30 - 50
Air spray	80 - 120
Airless spray	200 - 250

II-2.3.4 Paint application control :

Certain controls are required on both application and the surrounding atmosphere where the painting is being performed. Among the most important controls are:

* Temperature which is an important factor for drying time; it influences solvent evaporation. It also has an influence on relative humidity. Steel and air temperatures are taken into consideration for calculation of the dew point. This is important to know for avoiding the condensation of water on the surface to paint.
* Relative humidity is measured with a hygrometer in the area where the painting will take place.

Taking into consideration the temperatures both of the steel and the surrounding air and the relative

humidity, the dew point is calculated through given tables and a decision is issued whether the painting will be conducted or not. When the temperature of the steel surface is 3oC less than the dew point, the painting is cancelled until the appropriate conditions will be adequate to continue the work.
* Other conditions related to the surface preparation are as follows: the first coat of paint should be applied with as short a delay as possible; the contamination of the wet surface with dust falling from blasting, water spray, or any other undesirable object may affect the paint quality or the objectives needed; the planning of other work should be well scheduled to avoid the overlap of certain operations which can not be done while the painting is being performed.

II-2.3.5 Film thickness :

Monitoring the film thickness of paint during application is required and the method of measurement and the interpretation of the results should be agreed by all the parties involved (owner, yard, painting contractor and the paint supplier). The recommended thickness is always supplied with the delivery of the paint in the technical data sheet. It should be respected because too low a film thickness gives a poor corrosion protection and too high a film thickness may lead to solvent entrapment, resulting in slow drying and incorporation of air and bubbles in the film.
* The mean wet film thickness can be calculated from the quantity of liquid paint applied to the object to

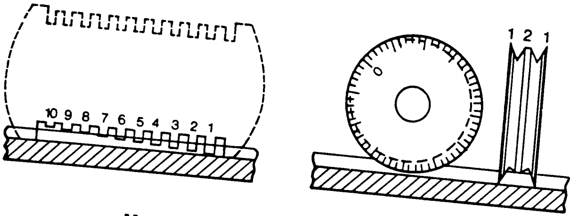
be painted and the surface area of the object. The quantity of paint applied is the difference between the quantity of paint actually used and the paint losses which depend on the different methods used. Two variables are necessary for dry thickness calculation viz:
Paint density and solid content in such a paint.

The formulae used for dry film thickness is:

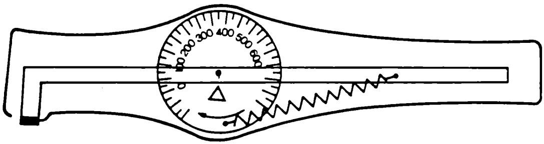
$$\text{Thickness } (\mu M) = \frac{100-X}{100} \times \frac{10 \times nV \times G}{d \times F}$$

X = Paint loss as a percentage of the total amount of paint used.
nV = Volume percentage of solids in the paint.
G = Amount of paint used in Kg.
F = Painted surface area in M2.
d = Specific gravity of the paint.

Measurement of Wet and Dry Film Thickness



Measurement of wet film thickness



Measurement of dry film thickness

Type of coating	Name of the paint	No of coat	Total D.F.T (μ)	Remarks
Oleoresinous	Oleoresinous A/C	3	120	
	Oleoresinous A/F	2	90	
Bituminous (Viny-tar)	Bituminous A/C	3	120	HB Type 160-240μ 2-3 coats
	Bituminous A/F	2	90	
Chlorinated Rubber	Chlorinated Rubber A/C	3	120	HB Type 120-200μ 2-3 coats
	Chlorinated Rubber A/F	2	90	
Vinyl	Vinyl A/C	4	100	HB Type 120-200μ 2-3 coats
	Vinyl A/F	2	90	
Epoxy	Epoxy A/C	2	200	
	Epoxy A/F	2	100	
Tar-epoxy	Tar-epoxy A/C	2	250	
	Binder coat	1	40	
	A/F paint for Tar-epoxy A/C	2	100	
Self-polishing	Tar-epoxy A/C	1	125	Film thickness is subject to change owing to expected service life.
	Vinyl-tar A/C	1	75	
	Binder coat	1	50	
	Self-polishing A/F	3	250	

A/C : Anti-corrosive
A/F : Anti-fouling
D.F.T. : Dry Film Thickness (microns)
HB : High Build

STANDARD PAINTING SCHEME FOR THE UNDERWATER HULL

(Source : CHUGOKU MARINE PAINTS, LTD)

II-2.3.6 Supervision and inspection :

The quality of the paint work depends on the quality of supervision. Every step should be carried out with close examination and well reported in written form. To avoid misunderstandings between concerned parties, agreements or arrangements to ensure good painting work must be well specified in as much detail as possible. Supervision and quality control are carried out by competent and experienced personnel who will attempt to improve matters by drawing to the attention of personnel difficulties that may arise rather than allowing such problems to occur. Specialized organizations provide highly skilled inspectors or supervisors to ensure the specifications between the parties are followed.

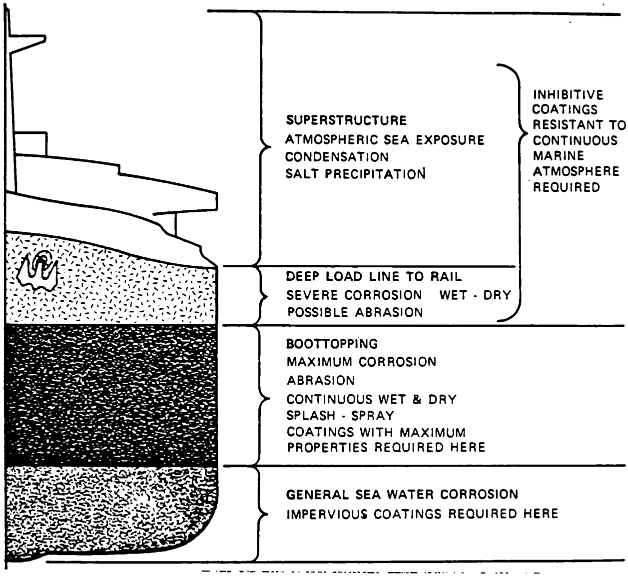
II-2.4 SAFETY REGARDING THE USE OF PAINT :

The International Convention for the SAFETY OF LIFE AT SEA of 1974, as amended, restricts the use of combustible materials in regulation 34 chapter II-2. It said:

"Paints, varnishes and other finishes used on exposed area interior surfaces shall not be capable of producing excessive quantities of smoke and toxic product."

The materials used in the protection of ships from corrosion and fouling and the process involved in their use both incur specific hazards to health and safety. the hazards include toxicity of paint components during application and removal and other liquids and their vapors associated with the work, explosion hazards from mixtures of solvent vapors or dust with air, while painting or preparing. Since the hull painting is carried mostly in open air, ventilation should be sufficient to prevent the concentration of solvent vapors from reaching the lower explosive limit (L.E.L).

Attention should be paid to National Standards relating to the limits of amounts of toxic materials to which the operators are exposed either as time weighted or short term limits.


SUPERSTRUCTURE
ATMOSPHERIC SEA EXPOSURE
CONDENSATION
SALT PRECIPITATION
INHIBITIVE COATINGS RESISTANT TO CONTINUOUS MARINE ATMOSPHERE REQUIRED
DEEP LOAD LINE TO RAIL
SEVERE CORROSION WET - DRY
POSSIBLE ABRASION
BOOTTOPPING
MAXIMUM CORROSION
ABRASION
CONTINUOUS WET & DRY
SPLASH - SPRAY
COATINGS WITH MAXIMUM PROPERTIES REQUIRED HERE
GENERAL SEA WATER CORROSION
IMPERVIOUS COATINGS REQUIRED HERE

II-3 CATHODIC PROTECTION

II-3.1 HISTORIC :

It was in 1824 when Sir **HUMPHREY DAVY** had used small buttons of zinc, or iron nails, attached to the protective copper sheathing installed on the hulls of the wooden warships; he was able to arrest "the rapid decay of the copper". This system was the beginning of the cathodic protection applied to the ships avoiding the loss of the metal which was initially used to strengthen the wooden hull.

II-3.2 DEFINITION AND OBJECTIVE :

As explained earlier electrochemical corrosion results from, or is accompanied by, a flow of current between an anode and cathode. It should be possible to prevent corrosion by controlling the flow of corrosion currents. The ultimate objective is to suppress all current flowing from the anode to the cathode in the corrosion cell. This can be accomplished by applying current from an external source so that current will be made to flow to, instead of away from, the original anodic surface.

II-3.3 SYSTEM :

To accomplish that objective, the external source of the protective current must be at a higher potential than is that of the anodic surface to be protected. The amount of current needed depends on the requirement to support a cathodic reaction over the whole of the surface to be protected. To generate that protective electron current, two main systems are commonly used:

II-3.3.1 Impressed current :

In an impressed current system of cathodic protection the current can be supplied from such sources as storage batteries, rectifiers, or generators depending on convenience and the amount of current required. The anodes must be designed and installed so as to take into account destructive mechanical forces that they may encounter. They may need a streamlined shape to minimize the drag effect. Mostly, platinum anodes are used in that system; other types of anodes are also used such as titanium, tantalum and niobium sheathed with platinum or plated with platinum.

The current required for protection is automatically controlled by electronic devices which change the amount of current needed to maintain the polarized potential of the protected metal within the desired range. This changing is dependent on the sailing conditions, geographical situation, water properties and also damage to the paint.

If an impressed current system is adopted, adequate trained and skilled crew are required for the monitoring of the system.

II-3.3.2 Sacrificial anodes :

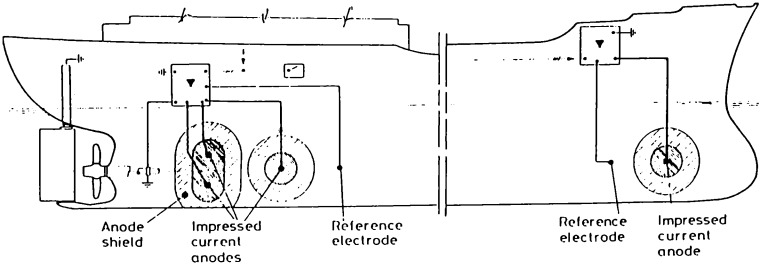
Sacrificial anodes are blocks or strips of metals which are less noble than the metal to be protected and have a lower potential in sea water. They are normally welded in appropriate parts of the hull to get the optimum effect; thus a galvanic cell is artificially made. The electrons flow directly from the anodes to the object to be protected. In supplying the protective current, the anodes are gradually consumed and therefore they have to be monitored for periodic renewal. The metals commonly used for sacrificial anodes are: zinc aluminum and magnesium. When in use, the anodes should be consumed uniformly and must have a long service life. To meet these requirements, different alloys are made with those metals in appropriate proportions.

II-3.3.3 COMPARAISON OF CATHODIC PROTECTION SYSTEMS :

The table below shows the advantages and disadvantages of the two differents systems applied of the cathodic protection (impressed current and sacrificial anodes).

COMPARAISON OF CATHODIC PROTECTION SYSTEMS

IMPRESSED CURRENT	SACRIFICIAL ANODES
ADVANTAGES	
1- If sufficient voltage is available the protection current can be increased to any desired amount, as long as the anode material remains functional 2- Most attractive for large ships, provided the system functions well and is fully automatic. 3- The anodes are designed to have a service life of at least 10 years. 4- Anodes attached to the hull; will not increase resistance. 5- Applied in combination with a high-duty paint system, extention of docking intervals may be permitted.	1- Can be used where there is no power. 2- No initial outlay for power equipment. 3- Relatively foolproof and little supervision required. 4- Current can't be supplied in the wrong direction with conseqent promotion of corrosion instead of protection. 5- Installation is simple. 6- Practically no risk of damage to the paint system due to overprotection. 7- Requires attention only during dry-docking.
DISADVANTAGES	
1- Installation requires expert knowledge to fit such system. 2- In case of failure or malfunction of the installation, serious risk of damage to the paint system results. 3- Requires continous regulation and appropriate adjustment.	1- Attached to the underwater hull, the resistance of the ship is increased by 0.5%. 2- The anodes are designed to have only a service life of 2-4 years. 3- Even applied in combination with a high-duty paint, no extention of docking is permitted.



- Impressed current system installation on a ship, position of the impressed current anodes and reference electrodes.

II-4 COMBINATION OF PAINT AND CATHODIC PROTECTION :

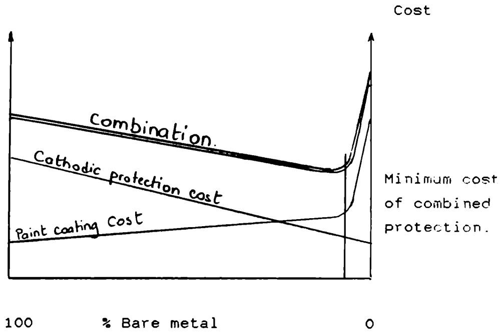
II-4.1 GENERAL:

Ships are normally protected against rusting by several coats of anti-corrosive paint. Sometimes, small defects and damages can occur in the coating baring the metal; thus the corrosion will be suitable to occur in that bare (weak) field. The combination of paint with cathodic protection is avantageous because such problems may be tolerated. Then the protective current will be concentrated at defects in the insulating coating. If only paint is used and any defects occur, it must be quickly detected and repaired; in such case drydocking is required and time is wasted. The combination of both paint and cathodic protection will be successful because of the whole potential of the hull and the flow of current which is applied.

II-4.2 COST CONSIDERATION :

An absolutely tight coating costs much more in production, application and maintenance than a coating covering, say, at the efficiency of 99% of the surface. The cost of cathodic protection is considered to have a linear variation with the exposed area of the metal. The combination of the two protection methods results in minimum cost for the optimum protection. Considerable savings can be made with the option of two alternatives combined rather than one system taken alone.

A schematic representation of the two separate alternatives with their combination is shown, giving the comparative cost in different manners.



A schematic representation of minimum cost obtained by a combination of paint coating and cathodic protection.
(corrosion and protection of metals, Gosta Wranler)

II-4.3 PAINT CHOICE WITH CATHODIC PROTECTION :

II-4.3.1 Fact :

The cathodic protection current causes electrolysis of sea-water in contact with underwater plating. Hydroxyl ions accumulate over the protected cathodic surface, where the conditions become alkaline and harmful to some paints. Results show the binder begins to soften and blister. In severe cases, complete disruption of the paint film occurs. Some paints are decomposed or simply saponified by alkali.

II-4.3.2 Choice :

Accordingly, protective coatings used with cathodic protection should resist alkali attack. The risk of damage to the coating around anode is greater than that of a sacrificial metal anode system, due to the possible over protection caused by the the higher density of current. The part around anode should be coated with a specific heavy duty coatings, such as coal tar epoxy paints. In order to establish the catodic protection in practice, the potential should be kept around the values: (-800 mV to -1,000 mV); because of the potential of the steel in sea water which is: (-770 mV to -790 mV).

Coating System	Potential level required
Oil-Based	-800 mV to -900 mV
Chlorinated Rubber	-800 mV to -950 mV
Vinyl	-800 mV to -950 mV
Heavy Duty (Coal Tar Epoxy)	-800 mV to -1,000 mV

(Source: Chuguku Marine Paints, LTD.)

II-5 ANTIFOULING :

Most antifouling coatings incorporate biocides, such as copper and its compounds, to control fouling by poisoning the growths, but other biocides such as lead, mercury and arsenic are still used. Paints must, therefore, be formulated to contain sufficient amounts of the toxin to allow a reasonable life for the antifouling paint and to allow it to leach out at an appropriate rate. There are two types of paint used:

- The continuous contact type in which the paint matrix remains unattacked and the toxic particles are leached out at the required rate.
- The soluble matrix or self polishing type in which layers of paint containing the toxin are removed to provide the required amount of poison. This method has an advantage because by the use of suitable coloured layers it is possible to provide an indication of when the antifouling paint requires replacing.

Antifouling paints should never be used with a metal substrate because of the possibility of galvanic corrosion. They are applied in one or two coats after the anti-corrosive coating system has been completed. Antifouling paints are to be applied shortly before the ship is launched because most of the antifouling paints cannot be exposed to the atmosphere for long periods. Nowadays modern paints have better weathering resistance. The paint manufacturer's directions as to drying and exposure time should be closely followed.

The choice of antifouling paint will be determined by the operating conditions of the ship, the time between dockings and cost. The life of the coating will depend upon the type, thickness and operating conditions and will vary from one to three years.

The antifouling paint is considered harmful and dangerous to the marine environment in the long term. As we have seen previously, fouling is combatted by so-called poisons which are used in the antifouling paints. These poisons inhibit the growth of or simply kill such undesirable species and algae attached to the underwater hull. Most of these poisons are mainly TBT (TRI-BUTYL-TIN) where in some countries legislation restricting its use is most severe. To meet the requirements in the market, new coatings have been developed by the well-known company INTERNATIONAL PAINT in the USA. It is TBT-FREE. The response to this new antifouling paint by the shipowners was immediate and highly encouraging. In the USA, whenever antifouling paint is being used, it should meet the ENVIRONMENTAL PROTECTION AGENCY regulations in regards to the release rate of TBT in the coating, in addition to its manufacture, sale and distribution.

* CHAPTER THREE *
MAINTENANCE

III- MAINTENANCE :

III-1 GENERAL :

Maintenance is a term used in the sense of keeping an existing system in good condition. In the long run, all systems develop defects. In paint systems, the defects can be mechanical damage, chalking, discolouration, cracking, flaking and chemical or biochemical deterioration. These defects cause deterioration of the substrate by corrosion formation.

In order to prevent paint systems from failing in their functions in the long term, periodic maintenance must be undertaken. The interval between subsequent maintenance operations can be extended by better pretreatment and by use of better quality paints. Permission for longer maintenance intervals is usually granted by classification societies to shipowners who protect the underwater hull of their ships by means of a cathodic protection system based on impressed-current, in conjunction with a high performance paint system.

In recent years, there has been a tendency to reduce maintenance, because of the new high performance paint systems requiring less maintenance than conventional paint systems.

As a ship out of service constitutes a considerable expense, shipowners endeavor to keep docking times to a minimum. There is an increasing practice of removing fouling and applying fresh antifouling paint during short dockings interposed between dockings for extensive maintenance. It may be for one day when a dock with adequate equipment to handle the work comes available.

III-2 PLANNING :

The most important part in maintenance is the planning which should be realized by close cooperation between shipowner, yard, paint contractor and paint manufacturer. The data needed for the maintenance work should be available before the ship goes into dry-dock.

A ship's report on previous dockings may give useful information to obtain maintenance data. Immediately after arrival of the ship in the yard, the areas where maintenance is expected to be necessary must be inspected. On the basis of this inspection, it must be decided as quickly as possible which parts of the ship need maintenance, how this is to be performed and which areas of the surfaces concerned should be repaired; repair of these areas should either be local or total, depending on the extent of the damage.

III-3 REPAINTING :

III-3.1 LOCAL REPAIR :

With local repair, it is essential to rebuild the paint system to a sufficient thickness; this is of special importance for the anti-corrosive coatings. Maintenance should not be postponed without good reason, since this will considerably increase long-term costs. The best practice is to undertake maintenance as soon as possible after the appearance of serious defects such as rust, blisters, cracks or flaking. To keep maintenance costs to a minimum, it is strongly recommended that so-called "preventive maintenance" be undertaken during service. For this purpose a maintenance paint schedule should be on board.

It is often difficult to estimate the total area to be repaired. The extent of any defects can be estimated only by thorough cleaning.

Generally the area to repainted is much larger than the actual area of rust spots and other visible defects, and moreover strongly depends on the distribution of these defects over the surface. It is important to completely remove not only the clearly visible defects but also any underrusting and poorly adhering paint surrounding these defects before touching-up the paint system.

The shipowner and the yard manager must agree on the extent of the maintenance work before it is started. The estimation of the extent of maintenance requires considerable skill and experience.

In local repairs every new coat of paint should overlap the previous one. Often, after the primer and intermediate coats are applied locally at the repair spots, the last coat is applied over the whole surface. In order to obtain good adhesion of the repair coat it is sometimes necessary to roughen the existing paint system at the paint manufacturer's direction.

Maintenance works poses more problems than new painting, because the surface preparation is often more difficult. The result is also dependent on weather conditions. Maintenance paints for local repairs should be compatible with the existing paint system. The paint manufacturer is able to supply suitable paint for application on the old existing paint.

III-3.2 WHOLE UNDERWATER HULL REPAIR :

Maintenance of the underwater hull involves removal of fouling, rust, salt and defective paint layers, and the renewal of the paint system at these spots. The smoothness of the surface should be restored so as to keep frictional resistance to a minimum. The underwater hull should be degreased with appropriate detergent followed by spraying the surface with clean fresh water.

As soon as the hull is dry, it should be freed from any adhering rust or hard fouling, and from blistered or cracked paint coats. For high performance paint system, blasting is the most effective and economical method used for large area.

The anticorrosive coats should be touched up as soon as possible after the above preparation; on the clean steel only, and should not overlap other existing coats. As soon as touched up areas are dry, a coat of antifouling paint should be applied to those parts of the underwater hull where it is needed. Care must be taken to ensure the antifouling application is not applied on the bare metal, otherwise contact corrosion can occur because of cuprous oxide contents.

After removal of fouling, rust and poor paint coats, the underwater hull sometimes still shows very rough parts. If this roughness is the result of repeated maintenance operations, the areas concerned should be cleaned to bare metal and the paint system completely renewed.

If the underwater hull is cathodically protected either by sacrificial anodes or impressed-current, the electrodes should be kept from being painted during the operation of painting. They should be covered with aluminum foil. They should never be covered with adhesive tape because tape can loosen at low temperatures, high humidity or during spraying.

III-4 MAINTENANCE OF THE CATHODIC PROTECTION SYSTEM :

III-4.1 SACRIFICIAL ANODES :

If sacrificial anodes are permanently attached to the hull, they should be inspected during every dry-docking. A check should be made that all are present and are still in proper electrical contact with the steel plating; wastage should be estimated, after removing corrosion products by wire-brushing where necessary. If the anodes cannot be removed, an approximation can made by measuring their dimensions and calculating their volume. The remaining life of the anodes can be estimated from these results. If it is considered that the life of the anodes is insufficient to cover the period until the next docking, they should be renewed or additional ones added.

III-4.2 IMPRESSED-CURRENT :

The maintenance of impressed-current installations is best undertaken by the suppliers. The anodes and reference electrodes must be inspected, and repaired or renewed as necessary. Careful control of an impressed-current cathodic protection installation is essential. A badly devised or imperfectly controlled system may do more harm than good. In addition, control is necessary to ensure that the system is operating at its maximum economic efficiency. Expert advice should be sought, where necessary, regarding methods of protection and installation arrangements.

III-5 INWATER MAINTENANCE :

Development in underwater inspection and underwater cleaning and painting techniques during the seventies have also helped to reduce the need for dry-docking for the purpose of antifouling renewal. These new developments in underwater technology include hull cleaning, hydroblasting and underwater work tools such as "brush-kart", hydraulic polishing machines and painting equipments.

Underwater removal of fouling must be treated as a temporary expedient, because after cleaning processes, new plants are being generated from the remains of previous weeds. Brush-cleaning will remove everything and the surface will remain clean until recontamination occurs when the type of fouling is barnacles, worms and other larvae. The problem is entirely different when the fouling consists of algae. Algae roots penetrate into microcracks in the undercoats and grip there strongly. When they are inflicted with a shearing or "shaving" action at their foot, the brush leaves the roots in place. They grow quickly and regain their previous length in 2 to 3 months. Improvements in the brush-kart system has been designed not only to cut the algae but to uproot and eradicate them from the micro cracks. When ships are fitted with impressed-current systems, attention should be taken to switch off the system before divers commence underwater work of any kind.

* CHAPTER FOUR *
ROUGHNESS AND FOULNESS EFFECTS ON FUEL CONSUMPTION

IV- ROUGHNESS AND FOULING EFFECTS ON FUEL CONSUMPTION :

IV-1 GENERAL :

Fuel costs account for more than 60 % of the ship's running costs, and can soar up to 80 % on VLCCs and faster turn-round container vessels.

It should be the aim of every shipowner to keep surface roughness on a new building as low as possible and to keep the roughness increases as low as possible throughout the lifetime of the vessel.

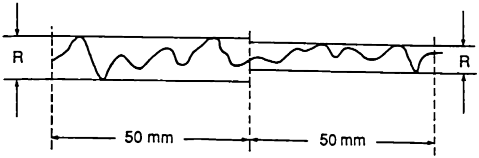
The British Ship Research Association (BSRA) was the first to concern itself with measurements of the hull surface roughness on ships. They studied the horsepowers needed to maintain speed.

IV-2 ROUGHNESS EFFECTS :

IV-2.1 ROUGHNESS MEASUREMENT :

The measurement positions are evidently taken over the hull wetted surface, the mean hull roughness, MHR, is measured from about a dozen 50 mm sampling lengths and expressed in microns. The average of the MHR values is the average hull roughness, AHR, and represents more than 1000 reading.

Roughness Definition



The mean hull roughness (MHR) is obtained from the separation of two parallel lines touching the highest peak and lowest valley in each 50-mm sample. The probe has a ball point with 1/16-inch or 1.56-mm diameter.

IV- 2.2 FACTORS INFLUENCING THE INCREASE OF SURFACE ROUGHNESS :

Every ship will leave the building yard with a certain degree of surface roughness. This roughness is called the ship's permanent roughness. The permanent roughness will increase with the age of the ship, depending on how the vessel is protected from corrosion, and how it is treated when dry-docked.

Among the most important causes of increased roughness are : corrosion and bad workmanship.

IV- 2.3 COST OF INCREASED ROUGHNESS :

In view of the present high bunker price it is very important to keep the underwater hull smooth.

Efforts have been made to work out a practical relationship between the increase in roughness and resistance or extra bunker costs, and the following rule-of-thumb can generally be used :

* **1 per cent change in power for each 10 microns increase in roughness from the newbuilding value up to a value of approximately 250 microns.**

* **From 250 microns and above, 0.5 per cent increase in power for each 10 microns increase of roughness.**

" The relationship between speed and shaft horsepower(shp) before and after grit blasting and repainting of one tanker of 35,000 dwt was measured. The results are as follow :

Before	: 756 microns
After	: 266 microns

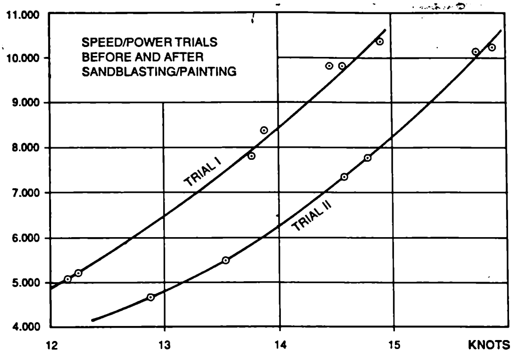
The reduction in roughness : 490 microns

* By the rule of thumb method, this gives a reduction in horsepower of :

$$\frac{0.5 \times 490}{10} = 24.5\ \%$$

Trials are done before and after grit blasting, the figure shows the increase of power versus the ship's speed. Through the graph, at 14 knots, the reduction of power from trial I to trial II is :

$$8500 - 6300 = 2200 \text{ SHP}$$



If we compare with the trials, a close agreement between the calculated and measured reduction is shown for for the power reduction.

If we look the fuel consumption side, and as we know the function of fuel consumption versus speed is logarithmic function and we can assume in any 2 nearest points in any position in the curve is considered as straight line and this give the decrease of fuel consumption of:

8500 ⟶ 100 % fuel consumption

6300 ⟶ x ? = 74 %

The decrease is about 26 %."

IV-3 FOULING EFFECTS :

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IV-3.1 FOULING FACTS :

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The case which has be seen in previous paragraphs was only related on hull roughness effect on power loss and fuel consumption increase. Although the fouling effect is much higher than roughness effect.

* Table A shows the loss of speed by foulness during 30 months time for one tanker of 270.000 dwt.

* For the same ship, table B shows the loss of speed versus the hull roughness.

Through these tables we can say the most important factor is fouling rather than roughness. In this case attention should be more focussed for fouling monitoring rather than roughness.

* On graph C, the curves show the comparison increase of power required for propulsion versus the fouling and roughness.

IV-3.2 FOULING COMBAT :

To avoid fuel consumption, the most important factor to combat as we have seen is " FOULING ".

In chapter II, fouling must be combatted either by :

* Antifouling paints which can be applied during drydocking operation.
* Or inwater cleaning by "brush-kart" which offers numerous advantages :
  - Fast execution.
  - Inwater cleaning operation, which is applied during loading/unloading alongside a pier, or at anchorage. This method does not involve any delay in the ship's operating schedule and good results are achieved.

COMPARAISON OF SPEED LOSS BY FOULING AND ROUGHNESS ON VLCC 270.000 dwt

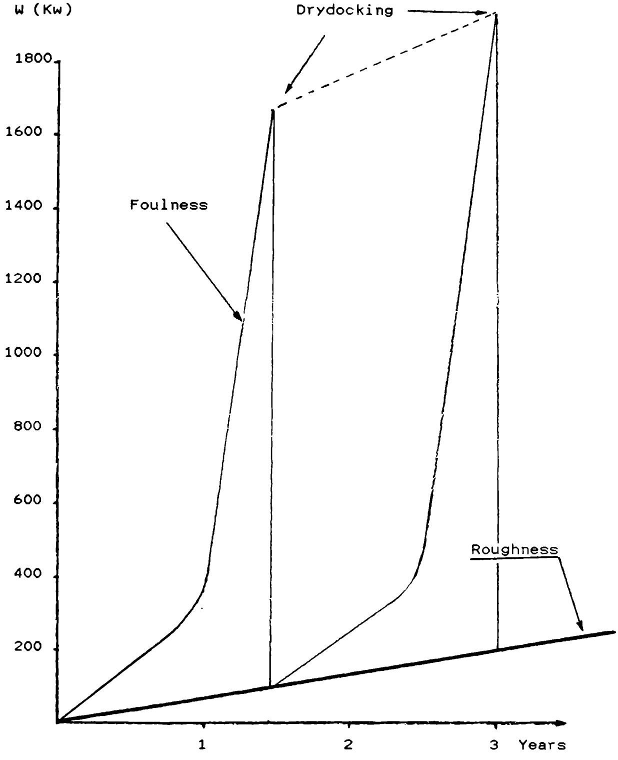
(source : maintenance lecture .)

TABLE : A

SPEED (Knots)	LOSS OF SPEED BY FOULNESS VLCC 270.000 DWT (Knots)				
	6 months	12	18	24	30
8	0,079	0,133	0,164	0,193	0,207
10	0,176	0,292	0,359	0,421	0,452
12	0,333	0,547	0,669	0,780	0,836
14	0,563	0,912	1,106	1,280	1,367
16	0,877	1,394	1,676	1,921	2,044

TABLE : B

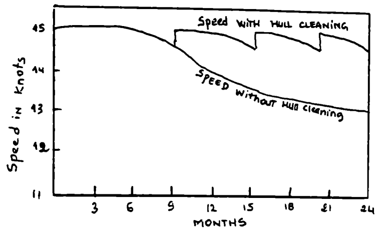
SPEED (Knots)	LOSS OF SPEED BY ROUGHNESS VLCC 270.000 DWT (Knots)				
	0 year	2.5	5	7.5	10 years
8	0	0,007	0,014	0,021	0,028
10	0	0,015	0,031	0,046	0,063
12	0	0,03	0,06	0,089	0,12
14	0	0,051	0,105	0,153	0,207
16	0	0,082	0,168	0,243	0,329

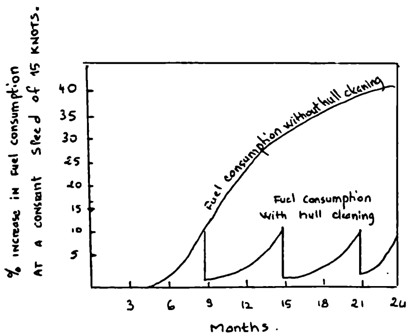


INCREASE OF POWER REQUIRED FOR PROPULSION
VLCC Speed 14 Knots ballast.

IV-3.3 FOULING EFFECTS ON SPEED AND FUEL CONSUMPTION :

The first figure shows the speed variation at a constant fuel consumption, both with scheduled cleaning and without, but the second figure shows the required increase in fuel consumption to maintain 15 Knots constant speed, again with scheduled cleaning and without.





IV-3.4 COST OF FOULING COMBAT :

IV-3.4.1 PAINT APPLICATION COST :

* Drydocking cost is evaluated knowing that in-docking and out-docking plus one day drydocking is calculated using a formula which is today used in a north European countries. The formula is :

$$0.047 \times LOA \times BM \times DM \quad \text{in US \$}$$

and for each extra day by :

$$0.023 \times LOA \times BM \times DM \quad \text{in US \$}$$

where LOA : length overall
BM : breadth
DM : depth

* Off-hire
* Paint price (including surface preparation and paint application)
* Running cost

IV-3.4.2 INWATER HULL CLEANING COST :

One table was dressed showing the average cost for hull cleaning by "Brush-Kart" system according to the size ship and the main draft during the cleaning operation.

RATE SCHEDULES WITH USE OF BRUSH-KART :

The average hull cleaning cost around the world .

(Source : Phosmarine equipment S.A.)

LBP (m)	MAXIMUM MEAN DRAFT				
	12m & less	12-15m	15-18m	18-21m	21m- above
150	US$ 5,503	US$ 6,636	US$	US$	US$
170	5,835	7,322	8,695		
180	6,407	8,008	9,496	11,097	
200	6,864	8,580	10,296	12,012	13,728
210	7,436	9,152	11,097	12,928	14,758
230	7,894	9,953	11,898	13,843	15,788
240	8,466	10,525	12,699	14,758	16,932
260	8,924	11,212	13,385	15,673	17,961
275	9,496	11,898	14,300	16,588	18,991
290	10,068	12,584	14,987	17,504	20,020
300	10,525	13,156	15,788	18,419	21,050
320	11,097	13,843	16,473	19,448	22,194
335	11,555	14,532	17,789	20,249	23,224
350	12,127	15,216	18,190	21,165	24,253
365	12,699	15,788	18,991	22,194	25,283

IV-4 CONCLUSION :

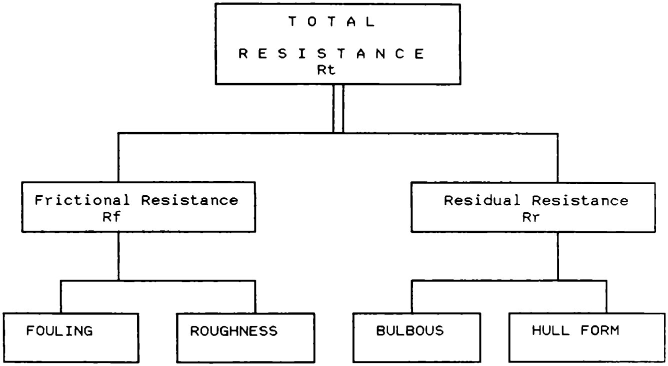
Economy is an important factor in today's ship operation. All companies have to struggle as best as they can by making efforts to keep their ships in as good condition as possible. The energy factor is the most important to look after. Fuel saving must be considered an important part of any company's objectives. The staff have to take concrete actions in different areas such as machinery performance, optimum ship maintenance, fuel consumption and fuel quality, hull efficiency, drydocking intervals and other parameters to achieve ship operating cost reductions. Monitoring and keeping the frictional resistance as low as possible in order to achieve better fuel saving which is an important parameter in operating costs. In any kind of vessel the fuel factor plays an important rule regarding the running costs. For example it is about 22 % in general cargo, 30 % in ro/ro and it can be much higher for fast container vessels.

Hull resistance which is determined as the total resistance of the vessel (Rt), has two components : frictional and residual resistance. The total resistance (Rt) could be expressed as :

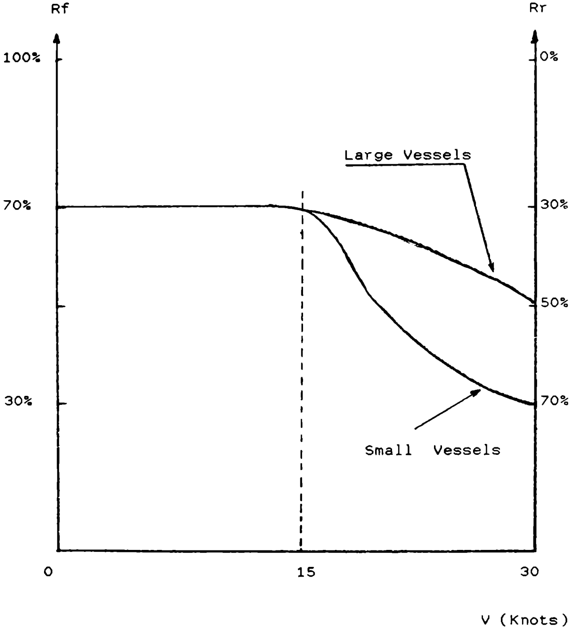
$$Rt = Rf + Rr$$

Rf : Frictional resistance arises due to the viscosity of the water and the hull friction.

Rr : Residual resistance is caused by the hull geometry.



(Source: Maintenance course.)


Rf
Rr
100%
0%
Large Vessels
70%
30%
50%
30%
70%
Small Vessels
0
15
30
V (Knots)

$$Rt = Rf + Rr$$

CHAPTER FIVE
MAINTENANCE STRATEGY

V- MAINTENANCE STRATEGY :

V-1 PAINTING STRATEGY :

Determination of the optimum underwater painting strategy involves collective consideration of a variety of technical, operational and commercial aspects. As fuel consumption is directly related to the performance of underwater surface coatings. In order to derive this strategy, it is necessary that sufficient knowledge and information must be available. In practice, it is most likely that gaps exist in this information and conclusion drawn from historic experience may not necessarily be totally applicable.

The process involves effecting hull underwater paint roughness surveys at regular intervals, usually at each drydocking, deriving the average hull roughness (AHR) value and, finally performing techno-economic computations for anticipated ship operating profiles for different painting strategies to obtain the relative financial differences over a period of time.

The policy of obtaining hull roughness readings at each vessel's in- and outdocking should be adopted. Roughness values can also be obtained from underwater surveys, but these results will be slightly different due to the effect of the cable between the measuring trolley and the analyser processing equipment. The two different reading methods are correlated within a certain accuracy.

Whether it is inwater or in drydock, the average hull roughness value involves at least one whole day work. The task is to tabulate the following:

* Overall average roughness of the vessel
* Average roughness values for the port and starboard flat bottom and vertical side areas.
* A sketch indicating the approximate location of where readings are taken.
* A table listing the roughness value at each location.

Advanced techniques for roughness data processing have been developed because of the great readings number often exceeding 5000 for a combined in- and outdocking survey. The roughness surveys are generally performed simultaneously with other parties. The overall results should correlate closely in order to achieve the maximum confidence limits within a certain accuracy. The accuracy increases with the number of samples taken, thus it is essential to capture as much data as possible. Roughness readings at all locations should be complemented by dry film thickness (DFT) measurements, especially in the case of vessels using self-polishing paint systems. Hull roughness survey data plays an essential part in formulating truly objective painting strategy. Unfortunately no concise rule can be given as the optimum paint is very much related to the specific vessel and her operating characteristics. At the current level of fuel cost, it can be shown that the cost of paint and preparation work is small in comparison with the final benefits that can accrue while the ship is in service.

V-1.1 COMPUTER IN PAINTING STRATEGY :

Nowadays many ready made SOFTWARE programs are available for all purposes in any special field. Related to the painting strategy many programs have been developed such as the CUNARD program, with chosen parameters related to the operational, technical and paint data fed into the computer. Its can give the optimum cost in a certain period of time, this will be useful for any decision making. In that program, relationships for power/speed, draught/displacement and power/specific fuel consumption of the vessel are taken into consideration. A subroutine allows for predefined roughness, and other, specified changes during periods in service between successive drydockings. The program also allows any individual value of basic data input to be changed. The related unknown parameters are automatically derived. For example, draught and speed are entered and displacement, shaft horsepower and daily fuel consumption are automatically derived. The program displays the scheduled drocking and related information such as time and cost in drydock, paint preparation and paint applied, with associated cost and a predicted value of hull roughness at undocking. The period is selected for eight years.

The department staff which has such computers with ready made program, will be able to work out a long-term plan for the hull of the each ship, based upon the hull roughness survey. A continuously reviewed policy for hull maintenance is essential if cost effective ship operation is to be maintained. The optimum policy may be impossible to determine or achieve but a partial solution should provide substantial savings.

The list of input and derived variables used in the CUNARD strategy program is:

DEEP DRAUGHT	(m)
L.B.P.	(m)
DISPLACEMENT	(m)
WETTED UNDERWATER AREA	(m2)
DATUM S.H.P.	(HP)
SPECIFIC FUEL CONS.	(gr/HP/Hour)
DATUM FUEL CONS.	(tonnes/day)
SURFACE PREPARATION COST	
PRIME PAINT COST	
A/C PAINT & APPL. COST	
A/F PAINT & APPL. COST	
IN- & OUTDOCKING HULL ROUGHNESS	(microns)
IN- & OUTDOCKING S.H.P	(HP)
INFLATION RATIO	(%)
CAPITAL EXPENDITURE RATIO	(%)
CAPITAL EXPENDITURE ADJUSTMENT	(%)

Other costs related to the discount % for NPV adjustment.

After complete processing with the program, display of the data output is as follow:

Current net financial status.
Current fuel consumption (tonnes/sailing day).
Net cost/m2 of paint system.
Cumulative miles sailing.
Cumulative fuel saving or penalty (tonnes).
Financial saving or penalty.

Collecting all the information needed for making or action taking or policy maintaining are the requirements of any manager who wishes and has to make profit within optimum standards of his company. Good management in control is efficient only when the information is maximum, policies are drawn, good definition and understanding of responsibilities are established and authorities and last not least the co-ordination between all concerned in the management of the ship is maintained. We can say that real control is only exercised by people who are in charge.

C O N C L U S I O N

The maritime institutions are exposed to a wide responsibility to satisfy or to try to approach the diversified parties in their maritime field. These parties should consider and participate when development or adoption of any new technology with all the parties dealing with or related to that matter. So, we can say, there is a big link between these parties. These parties can be as follow :

Maritime administration
Shipping companies
Port authorities
Ministry of education
Ministry of transport
Ministry of environment
International organizations/agencies (IMO, ILO, UNDP, WHO,...)
Manufacturers
Classification societies.
and all the institutions and organizations dealing with or related to the maritime field.

The maritime institutions should organize and arrange seminars or meetings for any kind of subject related to maritime field. All the maritime parties should participate for development or adoption any new matter. The maritime institutions are considered the heart of the maritime field if their roles are good and well prepared. From the point of view of better communication, the availability of buildings (classrooms, amphitheatre, workshops) and teaching aids (audio-visual, overheads, blackboards, photocopy machines) are suitable to implement all seminars.

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