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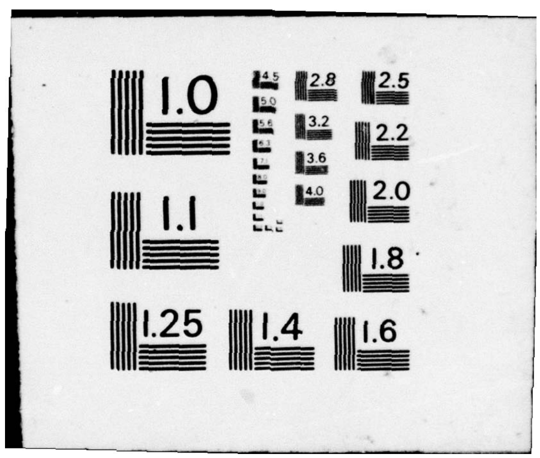
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# ONR LONDON CONFERENCE REPORT

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# OFFICE OF NAVAL RESEARCH

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4TH INTERNATIONAL CONGRESS ON MARINE CORROSION AND FOULING

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20 OCTOBER 1976

*US Naval Postgraduate School, Monterey, CA



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This 4th Int'l Congress on Marine Corrosion and Fouling at Juan-les-Pins, France, conference was attended by a wide range of specialists concerned with the behavior of materials in the sea. Broadly, two areas of concern were treated in two simultaneous sessions: (1) corrosion and corrosion-related topics, and (2) fouling. The deterioration of materials, either due to their demise electrochemically or due to their being used as a habitat for a variety of biota, is a central activity of the navies and maritime organizations of the world. Some 250 attendees came to the south of France during June to exchange notes on these very important topics.

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## 4TH INTERNATIONAL CONGRESS ON MARINE CORROSION AND FOULING

If one puts materials on, in or near the sea, they corrode and/or things grow on them. Such deterioration can be avoided by, for example, choosing materials which can resist the marine environment, or coating them with sealants and paints to protect them and poison the biota that tend to form on surfaces. In the south of France, during 14 through 18 June, at Juan-les-Pins, expensively located between Cannes and Nice, some 250 fighters against corrosion and fouling came together to discuss these matters. The conference was organized by the Centre de Recherches et d'Etudes Oceanographiques, with assistance of Centre Francais de la Corrosion under the patronage of Comité International Permanent pour la Recherche sur la Preservation des Materiaux en Milieu Marin (COIPM), etc.

The Congress was opened by Anne Woden, the General Secretary of COIPM, this group, which was formed in 1966, had the self-appointed task of concerning itself with the "Preservation of Materials in the Marine Environment." Though the first meeting of this sort was held in 1964, the Committee has, since its inception, taken over the responsibility of organizing the Congresses. The first meeting was held in Cannes, the second in Athens in 1968, and the third in Washington, DC, in 1972.

The conference has always been well attended, and the present one was no exception, 30 countries being represented. Of the 150 abstracts submitted, only about 80 papers were accepted for presentation. These were allotted 30 minutes each, so it was a busy week, indeed.

The first presentation, which was the plenary talk, was on the topic of hull condition. This paper, by R.L. Townsin and J.B. Wynne (School of Marine Technology, University of Newcastle upon Tyne, UK) and A. Milne and G. Hails (International Marine Coatings, UK) asked the question, "How important are ship bottom conditions?" The general conclusion was that hull roughness exercises an overall greater effect on ship's operating budget than does bad weather (See "On Keeping Our Bottoms Smooth," ESN-30-6). These workers further pointed out that hitherto unconsidered causes of roughness as well as the roughness due to poor paint application, contribute "budget deficiencies" which are non-trivial. One must, of course, calculate what it costs, for example, to grind-off the weld beads relative to fuel costs. Thus, the authors believe--and ably demonstrated in their rather comprehensive report--that all aspects of bottom smoothness must be taken into consideration when eliminating operating costs, a difficult calculation at best. Furthermore, the authors, who are naval architects and hydrodynamicists, considered other aspects of non-smooth, power-losing ship operation: for example, plate waviness. However, weld beads are more important still; and, again, they reminded the attendees that sloppy overspraying of paint could seriously decrease smoothness. With care it is possible to reduce surface roughness to 50 μm. Underwater scrubbing of weed can help, and hulls should be cleaned underwater by buffing pads instead of scrubbing brushes.

Following this plenary lecture, it was necessary for the attendees to separate into two groups: corrosion and biofouling.

Corrosion

There were more than 40 papers given in the corrosion category, ranging from metallurgical design of corrosion-resistant alloys to a wide range of corrosion protection schemes, including paints and cathodic protection. Half of the papers were in English and half in French, simultaneous translation and an extremely comfortable hall making the lectures rather pleasant (in spite of the fact that the local radio station would occasionally deliver music into the wireless earphones along with the translations).

The corrosion of cast aluminum bronzes was discussed by J.C. Rowlands and T.R.H.M. Brown (Admiralty Materials Laboratory, Holton Heath, near Poole, Dorset, UK). They showed that the metallurgical structure of this multiphase copper alloy can influence preferential phase corrosion. Electrochemical and standard metallography show that this sort of corrosion will be affected by thermal treatment. Typically, however, a thermal treatment that will improve marine corrosion problems will degrade mechanical properties. The performance of the systems which they discussed (Cu-Al, Cu-Al-Fe, Cu-Al-Mn, Cu-Al-Si, Cu-Al-Ni-Fe) cannot easily be generalized. However, they stated that for preferential phase corrosion to occur within these duplex copper-base treatment become of paramount importance.

Further on copper-based alloys, J.M. Krougman and F.P. Ijsseling (Corrosion Laboratory of the Royal Netherlands Naval College, RNNC, Den Helder, Netherlands) presented a paper on the seawater corrosion behavior of Cu-Ni-10Fe. Since this work was recently described in ESN 30-5:235, only a brief mention will be made here. The corrosion of the alloy is mainly controlled by an amorphous layer or corrosion product which is rich in Fe and Ni and depleted in Cu. Not unexpectedly, the protective properties of this film are dependent on the conditions under which it is formed: flow velocity, temperature, pH, chloride and carbonate content.

The protection against corrosion of deep marine structures was reviewed by J. Morgan (Morgan, Berkeley & Co., UK). Static offshore petroleum rigs are being moved into deeper waters. These structures are generally designed for a 30-year lifetime, and cathodically protecting them for almost any period would not be a problem if expense weren't an issue. But, as always, it is: so it is necessary to design cathodic-protection schemes. Also, weight in weight-critical structures can be considered--each zinc anode, for example, may weigh 800 pounds. Yet in spite of this weight there are structures currently in service which are fitted for a 30-year protection.

The way this has been done, according to Morgan, has been by extrapolation from much smaller structures to times much longer than corrosion engineers currently have experience with. In fact, zinc, the major anode metal used today for cathodic protection, has been in use only for some 25 years, and there is limited experience in the area of heavy anodes (several hundred pounds and greater) which are to be used for long times.

Morgan reviewed the task of the corrosion engineer in designing a cathodic-protection system for an offshore structure. The corrosion-current magnitude and distribution will, of course, be expected to change with time because of the addition of other structural elements to the underwater portion of the rig and the connecting-on of pipelines, which will generally be protected differently from the main structure. Added to this is the fact that the requirement of the anode (i.e., the amount of current) will change with time while the anode changes with size. An effective monitoring system is obviously called for. Thus, Morgan recommends a program of potential testing at appropriate intervals, so that, for example, impressed currents can be added to the already existent sacrificial anodes. Also, divers may have to swim in new or corrective anodes to improve the current distribution. In fact, Morgan stressed that what is really needed is an intelligent understanding of current requirements. He advocated the use both of sacrificial zinc anodes and impressed currents to achieve optimum corrosion control. The arrangements of the anodes and electrodes to obtain the correct polarization should be determined by models in the lab tanks. No mention by Morgan or others was made of computer modeling, but this approach could be a highly effective method of designing protection schemes.

The more mundane, but no less important issue of cathodic protection of pipelines was discussed by W.B. Mackay and L.R. Grace (UK). If the internals of shipboard oil or seawater-carrying pipelines can be cathodically protected, it will be possible to use mild steel pipes and also to require less frequent pipe replacement, now done on a scheduled costly and time-consuming operation. In fact, the large sea-going fleets are not using a cathodic-protection scheme on the inside of such pipes. These workers have reported large polarization levels for 12 to 15-inch-diameter pipes. It should be pointed out that a representative of the French Navy contended that they have used a similar technique for some time.

Brass alloys frequently corrode in seawater by a process of the leaching of the zinc from the alloy. This process of dezincification was elucidated in a paper by W.C. Fort, III and E.D. Verink, Jr. (Univ. of Florida, Gainesville), who, using Auger electron spectroscopy, were able to quantify the actual evolving zinc composition profile as a function of electrode potential. It was reported that the rate of zinc dissolution at each electrode potential is approximately constant, at least up to four days. Through a diffusion process of zinc to the surface, about 800 Å of surface layer are depleted in zinc after four days' exposure in a salt water solution.

The splash- and spray-zones are areas exposed to the sea which are most difficult to describe and protect. One obvious way to avoid serious attack of a structure at these regions is simply to clad the vulnerable structural member with a protective sheathing. Steel pilings, for example, are particularly cathodic in the tidal zone, and, therefore, INCO has suggested the application of a "noble," corrosion-resistant wrapping of Ni-Cu around the steel, covering the splash-zone area. R.W. Ross, Jr. and D.B. Anderson (INCO) reviewed the corrosion experience of steel pilings which had been protected in this manner. The long-term tests were carried out at the well-known Francis LaQue Corrosion Laboratory in Wrightsville Beach, NC, as well as other locations, and involved the emplacement of coated (tar, painted, galvanized or metal sprayed) and Monel Ni-Cu sheathed steel piles. After 20 years in the splash zones, the coatings were all considered to have failed, whereas the sheathed pilings showed no failure after 25 years. Actually, the coated specimens had failed well before the 20-year period. By the way, "failure," as defined here, is that rather qualitative condition "when the piling fails to function as such." (It should be noted that the Flame Spray Committee of the American Welding Society carried out 19-year tests of steel plate with coatings of flame-sprayed and vinyl-filled aluminum and zinc and found excellent behavior for a variety of zones and industrial environments.)

One further aspect of this particular paper warrants attention: Galvanic effects between different parts of the steel piling itself (e.g., between tidal and full-immersion zone) were found to be more significant than the effects of the couple between the steel and Monel sheath.

Additional papers on corrosion of various alloys in different environments were mostly either of handbook variety or so preliminary that they were of neither fundamental nor practical value, i.e., the corrosion of a range of aluminum alloys in artifical seawater; macro-cathodic reaction efficiencies for low alloy steels; new impressed-current devices for cathodic protection; etc.

There were, however, some innovative concepts which were discussed. For example, C.J. Sandwith and T. Breiwick (Univ. of Washington, Seattle) presented a paper on the cleaning of ship hulls with high-velocity ice particles. The idea of using ice for this purpose is clever, since ice, unlike many of the materials currently in use as blast-cleaning agents, is non-toxic, non-polluting and is readily-available. In their initial tests, these authors found that both crushed ice and solid ice are able to remove fouling and paint down to bare metal very effectively. Ice has an advantage over steel shot and copper slag since it is able to remove a greater mass of biofouling per shot. Also, significantly less energy per area of fouling surface-to-be-treated is required for the ice: 2/3 of that required for copper slag and 1/2 of that required for the steel. A similar energy-saving is noted for paint removal. In addition, ice leaves no pockmarks, which can adversely affect the to-be-painted surface. This idea certainly deserves further evaluation.

In two separate papers on metallization protection of mild steels, M. Leclercg (Vieille-Montagne, Belgium) and R. Bensimon (STE Nouvelle Metallisation, France) reported on the laboratory and field tests using an alloy coating of Zn-15wt.%Al. This coating, sprayed either by oxy-acetylene powder or the electric arc methods, has better marine-corrosion properties than either zinc or aluminum when used alone. The sprayed alloy, as discussed here, was given no post treatment (either thermal or by painting). The coating was on a rotating drum or on coupons, and the spraying was done manually. The results were indeed impressive. It might be noted that Leclercg and Bensimon have joined forces to present a variation on the above theme (with more metallurgical detail) at the Eighth International Thermal Spray Conference held in Miami, Florida, in September 1976. For NaCl, NaCl + $MgCl_2$, $CaCl_2$ (for alternate immersion or salt spray) the alloy coating performed better than either of the two base metals. Aluminum, in fact, showed greater porosity than either the alloy or zinc. In the case of alternate immersion studies, the cycle was 40 minutes for durations of over one year. Potential was measured during the immersion period of the cycle, and it was demonstrated that the alloy performed better than did zinc. It is interesting to note that in the American Welding Society long-immersion tests of mild steel panels, aluminum-sprayed and vinyl-coated outperformed other coatings, including zinc. The neglect of filling the sprayed aluminum with vinyl by these workers was a mystery to the observers. There was a stated avoidance of the use of metal-containing paints which, it was felt, might give rise to a galvanic couple and unpleasant corrosion products. How antifouling was to be achieved was not clear, however, and some discussion was held on the behavior of the alloy during use, while the zinc would be leached. The development of x-ray diffraction lines of aluminum seemed to suggest, not surprisingly, that the aluminum volume fraction was increasing at the surface. Some scanning electron micrographs were shown. This vague procedure only appeared to whet the audience's appetite for more analysis--which it did not receive.

Unfortunately, this gathering did not particularly satisfy the general needs of the corrosion specialists in attendence. Many of the works described were the results of long-time tests based on 20-year-old paint formulations. New paint systems in use today would certainly out-perform those used a decade or more ago. But such tests will always "out-date themselves." We need an accelerated marine corrosion test--one that can be trusted--and a corrosion conference of such a sort where problems will be openly discussed and their solutions sought.

## Biofouling

The fouling section of the Congress had 40 papers scheduled, but 10 of these were deleted due to non-attendance of the speakers. Some of the talks presented in the section dealt with a combination of fouling-corrosion topics and others with marine wood borers.

The first paper, by S. Johnsen and V. Rendbaek (Hempel's Marine Paints, Copenhagen, Denmark), dealt with a novel screening method for bio-active materials in antifouling paints. Over 300 bio-active materials were tested by a so-called 70% by volume toxicity test. The test proved simple, low cost, practical and fulfilled all the specific requirements of a screening method.

M. A. El-Malek and N. A. Ghanem (Laboratory of Polymers and Paints, National Research Center, Cairo, Egypt) discussed work in Alexandria which investigated the speculation that incorporation of rosin in a neutral binder might prolong the effective life and film properties of contact type antifouling paints in warm waters. The most successful formulations were those containing 65%-55% $Cu_2O$ with 27%-36%, respectively, rosin in a neutral binder.

The performance of antifouling paints in warm, tropical waters was reviewed by C. P. De, K. P. Buch, Y. P. S. Nirvan, and

F. M. Khandwawala (Naval Chemical and Metallurgical Laboratory, Bombay, India). In Indian waters, the vinyl based antifouling paint developed by the US Navy (U.S. Specification MIL-P-15931) has an effective life of only 14-18 months as compared to two-three years in American waters. Paints with longer lives can be formulated by increasing the loading of cuprous oxide (20%-50%) as well as rosin. The standard critical leaching rate of 10 $\mu g$ $Cu/cm^2$/day for an effective antifouling paint was considered to be on the lower side when used in Indian waters.

In recent years a number of antifouling paints have been formulated incorporating a variety of organo-tin toxins. For most of these formulations, such as the well-established types including tributyltinfluoride (TBTF) and triphenyltinfluoride (TFTF), the leaching mechanism is unknown. F. H. De la Court and H. J. De Vries (Paint Research Institute, TNO, Delft, the Netherlands) have investigated these two organo-tin toxins as well as triphenyltinchloride, tributyltinchloride, tributyltinoxide and tributyltinsulfide. They found that TBTF and TFTF are superior in potential toxicity to the other organo-tins studied; TBTF and TFTF would prevent fouling at a leaching rate of 1-2 $\mu g/cm^2$/day, whereas the others required more than 5 $\mu g/cm^2$/day to be effective. The leaching of TBTF appears to occur in at least two steps; first a degradation takes place (perhaps to tributyltinoxide), then the degradation products diffuse outward. TFTF was found to be a potentially superior toxicant, but it does not degrade and leaches only to a very small extent.

The designers, builders and users of high speed craft such as hydrofoils operating in sea water have found that the craft often encounters the simultaneous effects of marine corrosion, mechanical damage from water vapor implosion (cavitation), and accumulation of fouling growth during periods of low speed activity and docking. A. E. Hohman, Jr. (Vought Systems Division, LTV Aerospace Corporation, Dallas, TX) discussed the use of elastomeric coatings to protect against corrosion, cavitation and fouling. He reported on a technique for successfully bonding elastomers to metals which gives good protection from erosion cavitation and corrosion. However, when antifoulants are added to the coating, the energy-absorbing mechanical properties of the coating are markedly altered. For example, elongation resilience and recovery time can be reduced to such an extent that the coating loses its energy-absorbing properties. In addition, the toxicants leach at an accelerated rate during high-speed operations. We therefore have no really effective coating for hydrofoils at the present time that simultaneously gives protection from corrosion, cavitation and fouling.

At the 1972 Congress, T. J. Lamb (Engelhard Minerals and Chemical Corporation, East Newark, NJ) presented a paper on the control of marine fouling by electrolytic hypochlorite generation. At this meeting he gave an update on developments in the field of on-site sodium hypochlorite generation. In the last five years advances have been made to the point where many of the on-site generation systems are economical and practical for a number of users. A concentration of hypochlorite of 1 ppm in a sea-water system will completely control fouling; and the relative safety of using such systems (as opposed to liquid chlorine systems) make on-site hypochlorite generation attractive for fouling control in sea-water piping systems on offshore platforms and ships.

S. E. J. Furtado (Portsmouth Polytechnic, Portsmouth, UK) gave a resume of a paper submitted by J. E. Barnacle (Forest Products Laboratory, CSIRO, Melbourne, Australia) on the problems of wood preservation in the sea. Many species of plants used for timber possess natural resistance to marine borers, some untreated piles lasting 50 years or more in tropical waters. Many of these resistant woods contain appreciable amounts of silica, but the active principle that deters borers is probably a polyphenol. The treatment of wood with preservatives such as creosote or copper chrome arsenate is common practice in temperature waters, but in tropical seas the effectiveness of such preservatives depends heavily on the properties of the wood to be treated, and most sapwoods or softwoods deteriorate rapidly even when treated.

Also in connection with wood biodeterioration in the sea, P. Deschamps (CNRS, Paris, France) gave a short and very general paper on the biological nature of teredine and crustacean wood borers.

S. E. J. Furtado and E. B. G. Jones (Portsmouth Polytechnic, Portsmouth, UK) and J. D. Bultman (Naval Research Laboratory, Washington, DC) discussed the effects of wood extractives on the growth of marine microorganisms. They reported their evaluation of three compounds extracted from tropical woods (obtusaquinone, obtusastyrene and lapachol), on the growth rate, reproduction and spore germination of marine fungi, and the antimicrobial effect of these compounds on marine bacteria and actinomycetes isolated from wood. Obtusastyrene proved to be most toxic for all of the fungi and bacteria studied, whereas obtusaquinone was least toxic.

A long-term study on marine-fouling organisms and wood borers in the port of Civitavecchia was reviewed by E. T. Rivosecchi and C. Gusso (University of Rome, Italy). In addition to determining the nature of the fouling growth quantitatively and qualitatively they reported on aspects of ecological succession, seasonal settlement, substrate preference, and depth and horizontal distribution in the harbor. Wooden panels exposed in the harbor were attacked by *Limnoria tripunctata* and four species of teredines.

E. C. Haderlie (Naval Postgraduate School, Monterey, CA) presented a paper on the fouling communities in the intertidal zone on wooden and concrete pilings at Monterey, California. Distinct stratification or zonation of organisms was found to occur relative to tidal level, but wooden and concrete piles carried somewhat different populations, and piles on the eastern edge of the wharf exposed to more light and wave action were fouled by many organisms not found on the western side.

A. F. A. Ghobashy (Institute of Oceanography and Fisheries, Alexandria, Egypt) discussed the results of an extensive study on the seasonal variation and settlement behavior of the principal fouling organisms in the eastern harbor of Alexandria. This is the first such investigation in Egyptian Mediterranean waters.

It has long been suspected that competition might occur between the two major groups of wood borers in the sea, the Teredinidae and the Limnoriidae. A study focusing on such competition in the coastal waters of Hong Kong was reported on by L. F. Fung and B. Morton (Department of Zoology, University of Hong Kong). *Limnoria tripunctata*, the only crustacean borer of these waters, is never in competition for space with estuarine-dwelling teredines, but shares a range with *Lyrodus medilobatus* and *Bankia carinata*, and competition with these shipworms modifies the distribution, both horizontally and vertically, of both groups of borers.

Another study in Hong Kong harbor, reported by G. W. Green and B. Morton (Departments of Mechanical Engineering and Zoology, University of Hong Kong), dealt with preliminary fouling and corrosion of painted metals. The fouling community of Hong Kong is a mixture of temperate and tropical fouling organisms, and the community is strongly influenced by the water masses of the South China Sea and the outflow of the Pearl River. Fouling of unpainted surfaces was high, but corrosion of the surface reduced the growth considerably. Painted panels, using standard Naval Protective Paint, were protected from corrosion, and barnacles settled only on the edges.

The only paper presented at the Congress dealing with fouling in relatively deep water was one by G. Relini (CNR Laboratory of Metal Corrosion in the Sea, Genoa, Italy). The investigation involved placing experimental panels at 200 m depth off Punta Mesco east of Genoa in the Ligurian Sea and exposing them for 12 months before recovery.

No fouling occurred on copper, brass or cupronickel alloy panels, zinc panels were lightly fouled, and carbon steel panels had areas free of fouling due to corrosion products. Asbestos, PVC, stainless steel and aluminum were fouled in about equalarmounts and by similar organisms. On horizontal panels, different foulers settled on the upper and lower surfaces. The variety and total biomass of the foulers was far less than in nearby port water. In wooden panels exposed at 200 m depth, the borers *Zylophaga dorsalis* and, surprisingly, *Limnoria tripunctata* and *Chelura terebrans* were found.

A. Bubel, C. H. Thorp, and C. A. Fitzsimmons (Marine Laboratory, Portsmouth Polytechnic, Hayling Island, Hants, UK) gave a beautifully illustrated discussion on the results of a histological and electron microscopical study of opercular regeneration in the serpulid *Pileolaria granulata*, with particular reference to the formation of the calcareous opercular plate. As in earlier studies on *Spirorbis spirorbis*, a solid cuticle precedes the deposition of the calcareous opercular plate.

The inter- and intraspecific variation in seaweed fouling potential was discussed by G. N. Goodman and G. Russell (Botany Department, University of Liverpool, UK). Species of *Enteromorpha* were studied for evidence of variation in resistance to copper-based antifouling coatings. Plants of the same species collected from test panels coated with cuprous oxide antifouling paint showed greater resistance to copper than other plants collected from shore stations. The evolution of copper-resistant strains of *Enteromorpha* confer on them a relatively high potential for ship hull fouling.

R. L. Fletcher (Marine Laboratory, Portsmouth Polytechnic, Hayling Island, Hants, UK) reported on observations on some secondary attachment mechanisms in marine algae. Rhizoids from a variety of fouling algae adhere to the surface by the production of a distinct cementing material which is produced by the actively growing terminal regions of the rhizoid. This is the first report of the site of origin of the adhesive material.

The settlement and growth of ascidians on experimental panels exposed at Taranto (Ionian Sea) and Brindisi (Adriatic Sea) in Italy was described by A. Tursi, M. Gherardi, E. Lepore, and M. Chieppa (Institute of Zoology, and Biology Department, University of Bari, Italy). Initial settlement on asbestos panels was in densities far higher than in natural populations in the harbors. Competition for space and food soon reduced this initial population to one the area occupied could support. In the harbors studied, ascidians tended to settle on top of earlier fouling organisms such as serpulids, bryozoans and barnacles, and not directly on the asbestos surfaces.

R. W. Moncreiff, P. H. Benson and J. W. Graham (Lockheed Aircraft Service Company, Ontario, CA) reported on thermal-tolerance studies of two major fouling organisms, *Mytilus edulis* and *Balanus tintinnabulum* which often occur on the inside walls of cooling water conduits of coastal electric generating stations. An interaction between rise rate and temperature was found for large *Mytilus*. Between 30°C and 39°C a rise rate of 2.5°C/minute was most effective in causing mortality; outside these temperatures a slower rise rate was more effective. Thermal tolerance in *Mytilus* increased with animal size to a point, then decreased. *Balanus* showed no significant differences between sizes.

The effects of zinc and pH on the larval attachment of the erect bryozoan *Bugula neritina* was considered in a paper by P. H. Benson (Lockheed Aircraft Service Company, Ontario, CA). Both zinc and lowered pH had the effect of decreasing successful larval attachment, but zinc appeared to be the primary effector. The lowering of the pH to 6.0 in a thin boundary layer at the sea water-structure interface has the potential for an antifouling system with fewer environmental problems than those systems using heavy metal toxicants.

B. Moss (Department of Plant Biology, The University, Newcastle upon Tyne, UK) described the effects of underwater scrubbing on ship fouling algae. If the scrubbing is incomplete and removes only the upper part of the plant and leaves fragments of the holdfast, the subsequent growth of the algae is stimulated so that several plants grow from what had been one before.

A variety of techniques have been used in the past to remove fouling growth from marine structures and ships. One of the newest of these is the cavitating water jet, and the use of CAVIJET for fouling removal was described by A. F. Conn and S. L. Rudy (Hydronautics Incorporated, Laurel, MD). The method involves causing vapor-filled cavities to grow within a relatively low-velocity liquid jet. By adjusting the distance between the nozzle and the surface to be cleaned, these cavities are permitted to grow; they then collapse when the jet impacts the solid material. On collapse, extremely high, very localized stresses are produced which can remove fouling, paint and rust from ship hulls. Using various nozzles, and water at 2,000 psi or less, they have achieved fouling removal rates which are comparable to the hand-held sand-blasting methods now in use and at considerably less cost.

The study of the origin and nature of primary slime films has long been considered critical in attempting to understand marine fouling and how to control it. At this Congress three papers on primary films were presented. In the first of these, W. A. Corpe (Department of Biological Sciences, Columbia University, NY) discussed the general nature of primary bacterial films including the natural history of the organisms involved, the "conditioning" of the surface, the attachment of bacteria, the interaction of primary microbial films with soluble and particulate materials, and the relationship of primary films to the initiation of macrofouling. He also described known methods of interferring with the development of primary microbial films.

The second paper by S. G. Dexter (College of Marine Studies, University of Delaware, Lewes, DE) dealt with the influence of substrate wetability on the formation of bacterial slime films on solid surfaces immersed in natural sea water. He noted that the challenge in the control of microfouling or primary slime films may be in designing surfaces whose critical surface tension for wetting by organic liquids precisely matches that of the specific environment into which they are to be placed.

The third paper on microbial slime films was by S. M. Gerchakov, D. S. Marszalek, F. J. Roth and L. R. Udey (University of Miami, Miami, FL) and discussed the succession of periphytic microorganisms on metal and glass surfaces in natural sea water. Using beautiful scanning electron microscope photographs, the authors illustrated the various periphytic microorganisms that initially settle on stainless steel and glass plaques. The effects of dissolved organic matter and the surface-associated microorganisms on metal corrosion in the sea indicate that stainless steel surfaces enrich or select for potentially corrosion-enhancing bacteria.

E. Lindner and C. A. Dooley (Naval Undersea Center, San Diego, CA) presented the results of an extensive study on the reaction mechanism of the adhesive of balanoid barnacles. Model reactions were designed to elucidate the nature of the chemical species responsible for the characteristic absorption at 330 and 345 nm. The authors also examined the probability of the so-called autocrosslinking mechanism in which protein molecules become crosslinked through their tyrosyl side chains.

The relationship of biological activity of organo-tin (or lead) compounds from chemical structures (including cisand trans-isomerism) was discussed by D. A. Kochkin (University of Kalinin, USSR). The physico-chemical properties of several organo-tin and organo-lead monomers and the areas where they can be used as biocides were considered.

The last paper in the fouling section was by P. Picone and T. Z. Sertorio (University of Genoa, Italy) and described the abundance of barnacle larvae in Italian harbors. No attempt was made to determine the species or the developmental stages involved, but details on the percentage of barnacle larvae in the zooplankton collected at various times and in various harbors were presented.

## Conclusion

This conference, clearly aimed at the well-heeled scientist and engineer, was a mixed blessing. Unfortunately, there was only limited opportunity for open exchange of both an informal and formal sort. Furthermore, due probably to the very large registration fee and high prices on the summer French Riveria, most of the attendees were of middle-aged vintage. There is, of course, nothing wrong with being "senior," but it would have been nice to have had more junior individuals at the Congress as well.

On the other hand, the activity of protecting materials in the sea is alive and well. A large number of individuals are involved in trying to understand mechanisms of materials deterioration - and also attempting to do something about it. Conferences of this sort will help focus on the hot problem areas and, as such, are worthwhile.