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S Y N O P S I S

The problems encountered in the intake structures of most of the coastal installations by marine fouling has been alarming all over the world. This paper is an attempt to discuss the types of marine bifouling organisms, the damage caused by them to the coastal installations like steel mills, oil refineries, pumping plants,power stations, etc., the latest procedures and practices in the field of marine growth control and their application in typical situations.

Although the published information on this subject is rather scanty, an attempt here is made to carry out a comprehensive survey on the available academic material tracing the history of the work done in this field.

A lot of data on the chlorine production within the country was collected and a case study on the selection of mode of bifouling control for cooling waters of Karachi Steel Mill alongwith an economic comparison of the various measures and systems has been discussed.

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1.0 INTRODUCTION

The users of industrial waters, pump houses, power stations, sea water pumping plants, steel mills,and oil refineries, etc.,face a continuous source of problem from the growth of marine organisms,both plants and animal. In order to find a solution to such a problem, it is normally a first step to carry out investigations to determine the type of marine fouling existing at the coast from where water is being brought in. The information obtained after such an investigation is of tremendous assistance in finding means of control of marine bifouling. The developed countries which are highly industrialised in nature use different measures and controls for controlling marine bifouling. Amongst these, effects of heat shock treatment, chlorination, mechanical cleaning, toxic paints, high velocity, and more recently copper sulphate have been found to be used at various power plants in U.K., U.S.A., Japan and some of the Far East countries like Singapore and Malaysia.

The problem of marine growth control remain unsolved despite all the precautions and the measures taken against bifouling. The main reasons why we need to have sea growth fouling control is because firstly, as mentioned above bulkhead gates, travelling water screens, and related equipment are still subject to severe fouling. Secondly, hardshelled organisms grow very rapidly in the relatively small intake structures and are also able to attach themselves to the inside of pipes running at low velocity. Thirdly, corrosion and erosion of metal on the downstream side of shells lodged in the condenser tubes has always been a serious problem. Finally, high cost of labour and materials emphasise the importance of maintaining high condenser efficiency by eliminating shutdowns and the expensive manual cleaning of intake structures, piping and condensers.

In section 4.0, a comparison has been made of various means of controlling marine bifouling followed by a detailed investigation on one mode of control, chlorination which according to investigations carried out in various parts of the world is the most widely used method (3).

Section 2.0 includes a comprehensive literature survey on the problem followed by details of types of marine bifouling organisms existing in the world all over.

NESPAK has carried out certain investigations over the past couple of years regarding marine growth control strictly in relevance to the project,Karachi Steel Mill sea water supply system. In Section 5.0 comparative analysis of various marine bifouling controls and measures has been discussed.Useful information and data regarding chlorine production within the country was used in the economic analysis in section 6.0

2.0 LITERATURE SURVEY

Tracing the history of the work done in this field, we find that little has been published on the growth and control of fouling organism visible to the naked eye, whereas a lot has been said and written on the microorganisms as slime formers in heat exchange surfaces with attendent reduction of heat transfer efficiency.

In England, the first published work was the result of efforts at the Portobellow Generating Station, Edinburgh in 1919 on the control of marine growth. In United States, the first work was carried out by W.J.O.'Connell, Jr. in 1926 and three years later, control of marine growth was started at the North Point Station of Long Island Lighting Company. Both this work and the work at Corpus Chirsti, Texas proved that intermittent chlorination could eliminate the grasses and higher algae effectively to reduce the growth of bivalve forms (10).

Patten's report on the plant-scale work at the Lynn Gas and Electric Company plant at Lynn,Massachuretts was published in 1949, supplemented by a description of chlorination as a means of control from experiments conducted at Kure Beach North Carolina by Clapp, in the same year.

Although not enough research has been carried out in this field, it is the actual experience at all the power plants in various parts of the world which has guided engineers in designing workable control systems.In Pakistan, three research reports have been published so far by Institute of Marine Biology, Karachi University,the latest pub-

lished in November, 1975, giving some information on short duration chlorination for the intake structure of Karachi Nuclear Power Plant (6,7,8). The two earlier reports looked more at the settlement and control of marine organisms in cooling systems of coastal installations.

In the United States, at Lynn, some three hundred tons of mussels had to be removed annually from the inlet tunnels and enough shells broke loose from the mass in the tunnel to require cleaning the condensers each week for the removal of the debris which had collected on tube sheets. The growth if not stopped become so large that screens, tube sheets and pumps would become the main source of attack resulting in costly shutdowns, not to mention the additional labour required to clean up the mess caused by the organisms which were allowed to grow.

3.0 TYPES OF MARINE BIFOULING ORGANISMS

3.1 Barnacles

They are famous for causing fouling to ships' bottoms. In Pakistan, most recent barnacle fouling has been observed to cause serious trouble at the Karachi Nuclear Power Plant.

Barnacles were considered to be bivalve but now they are thought to be a closely related member of crustacean group which include the crayfish, lobster, and the soft-shelled crab. After hatching, the larvae get released in free swimming forms and after moulting into various forms, finally metamorphose into a form called a cyprid. This cyprid cycle lasts seven to fourteen days during which the organism remains a free swimmer, settle on a suitable surface and a shell is formed. If the light is too bright or too dark, the barnacle may move on before it settles down. Normally in exposed area, the barnacle life is three years and in less exposed areas, five years.

3.2 Mollusca

This family consists of snalls, single sheeled Gastropoda, clams, oysters, mussels and other bivalve organisms. Such type of bifouling is most dangerous and has

caused serious trouble in the British Isles, the North Atlantic and the Western coasts of the United States.The black mussel varies in size upto a maximum length of four inches. When the organism is completely submerged at all times, the greatest growth rate occurs. Optimum growth of Mytilus occur at a temperature of 50° to 60° F. The American Oyster is the Common Mollusca responsible for severe fouling of power plant inlets on the South Atlantic and in the Gulf coastal states. With its rough shell and white interior, it is easily recognisable and its life cycle is similar to that of the edible mussel.

3.3 Sponges

They look like a colony of individuals having a large number of pores on the outer surface. Food enters through water into these pores. Reproduction occurs by budding and results in a single sponge increasing in size or even dividing but does not permit the formation of new groups at a distance from the previous place of attachment.

The sponges are the simplest of the fouling organisms and are relatively sensitive to pH.

3.4 Bryozoa

They are often confused with sponges but actually they are minute colonial animals (4,5). Their appearance is in the form of red or white encrusting patches as groups of apparently dead or sticklike organisms, brown or purple in colour, projecting from a rock, or branched as sticks with plumed ends. South Atlantic and Gulf coast areas have a very rapid growth as Bryzoa Colonies are able to hibernate successfully and resume growth in early May. At one New England situation, this season was determined as between June 10 and November 15. Naturally, a lot depends upon water temperature. A power plant in New York, USA,first found trouble from Bryozoa in the tail pipes and discharge tunnels.

3.5 Tunicates

This type of fouling which is the highest type of fouling responsible for fouling water circuits,lies among

the chordates, which include fish, man and other mammals. The most common form consists of a brown sac with two distinct openings at the end of noticable tubes. They are normally observed at the roof of a water intake tunnel, commonly referred to as "squirt balls". This is so because of the water ejecting from their body cavities sometimes after they have been lifted from the water. Even this high animal can reproduce by budding and thus form extended colonies.

4.0 MEASURES AND CONTROLS FOR MARINE ORGANISM GROWTH

Various measures and control have been adopted for controlling marine bifouling. They are described below:

1. Hot Water Treatment
2. High Velocity
3. Chlorination
4. Toxic Paints
5. Copper Sulphate
6. Mechanical Cleaning
7. Combination of chlorination and Heat Shock Treatment
8. Combination of chlorination and high velocity

4.1 Hot Water Treatment

This method of treating marine bifouling is mainly used by the Edison Company of California in eight of their power plants which use sea water for cooling purposes. So far reports from this company do not indicate any complaints against this method. This Company, however, provides the usual treatment of intermittent chlorination for slime control in their condensers for keeping up their cooling efficiency. In the Sea Water Intake and Outlet System of Karachi Steel Mill, provision for heat shock treatment has been made through reverse flow of hot water from the condensers.

4.2 Effect of Velocity

Russian experts at the Steel Mill observe that one method of control of marine fouling organism is to provide velocities at which the attachment of larvae of the fouling organisms to the pipe surfaces do not occur.Normally such effective velocity is around 1.5-2 meters per second. Some of the coastal power stations studied by NESPAK Engineers, indicate that merely the use of high velocities is not enough in marine growth prevention. Although organisms can only attach if there is little or no current at the critical period, however, young barnacles have been observed to attach themselves even at a velocity of 2 meters per second. Once these growths stick it becomes difficult to remove them even if the velocities reach as high as 8 meters per second. This phenomenon is confirmed by the fact that barnacle growth is so strong at the bottom of ships that velocities of 20 meters per second fail to remove them. Similar observations have been found by Myers, Holm and McAllister (9) that many organisms can attach only if there is little or no current movement at the critical period of settlement.

As a matter of fact most of the fouling problems are encountered in pipelines or conduits from the pump house to the condensers. The disposal conduit or pipelines is not observed to present problems of marine fouling growth.Some of the power stations, especially in U.S. have been studied by NESPAK experts under this context and it was found that merely high velocities are not enough to prevent bifouling but chlorination combined with the high velocity, is definitely most effective.

4.3 Chlorination

Research, and the practice at most of the coastal installations, indicates that chlorination is the most widely used means of marine bifouling control. Normally, a combination of lower dosage of continuous chlorination is widely used. Continuous chlorination kills larvae and plankton of the fouling organisms preventing their attachment to surface. However, once these organisms get themselves attached to the surface, they form protective shells around them and shock dosage of chlorination or a combination of heat shock and

higher dosage of chlorine for shorter duration, is necessary.

Chlorination as treatment for marine bifouling is suggested for following reasons. Firstly, all marine bifouling do not have protection against poisons for a few hours or even days after they begin their life cycle. Secondly, once barnacles and tunicates have formed a shell, they can resist chemical poisoning for a relatively longer period of time but are only susceptible to killing by means of heat treatment. Thirdly, bryozoa, and sponges, which are the unshelled organisms, remain susceptible to poisons throughout their life cycle.

The magnitude of marine fouling is a function of chlorination and water temperature. Normally the following type of chlorination treatment is given in different situations.

4.3.1 Soft Forms of Organisms

Growth of mussels,bryozoa, barnacles, sponges and shines is only supported above temperature of $40^{\circ}F$ and can be treated with a chlorine dosage of 1.5 ppm in case of fresh sea water.

Intermediate chlorination is also used of a 1.0 ppm residual at the end of one hour contact time. Universally, the level of treatment adopted is once after every eight hours. The point of contact is normally ahead of trashracks etc.

4.3.2 Hard Shelled Organisms

Treatment in such cases is the intermittent application of chlorination of free available chlorine at low level. Free available residual at the tail ends of the pipes should be between 0.25 to 0.50 ppm during the growing season. Chlorination is recommended for a temperature above $40^{\circ}F$ in the growing season which is function of water temperature.

In a special report published in 1964 at Lynn (Massachusetts), it was indicated that the most effective control is by chlorinating to a 0.5 ppm residual at the

condenser inlet when the water temperature is above 40°F, usually from April 1 to December 15; requiring a 1.2 ppm dose. A dose of as high as 4 ppm is sometime used at the start of spring. This high dose may be needed for few days to remove slime accumulations built up during the period of no treatment and to obtain a residual throughout the system. The report concludes that if such a programme is carried out, inspections every five years reveal no mussel growths whatsoever.

Separate points of application and chlorine control equipment need to be provided to carry out intermittent chlorination for at least the length of time required for the water to flow through these other systems. Also chlorination should be done to the water in the long shutdown periods. Inlet structures and the chlorine solution diffusers must be carefully designed so that dead spots are eliminated, like sharp inside corners, manhole openings below normal water level, and deep crevices at pipe joints. Every surface should be workable by chlorinated water because if there are stagnent areas in the inlet structure, growth will occur despite the chlorinated water treatment.

4.3.3 Chlorination and Corrosion

Research (2,11) has been carried out to look at the adverse effect of chlorination on metals used in the plants in various parts of world. It was found that the use of continuous chlorination with residuals of 1.0 ppm or less was found to have no significant effect upon the corrosion behaviour of steel and many copper base alloys commonly used in power plant construction.

4.4 Toxic Paints

Toxic paints have been found to be in minimum use all over the world for controlling marine growth and no published data is available. NESPAK experts while visiting various power plants in USA, UK and Japan also found that at only one of the power stations at Florida, toxic paints were tried but failed to produce any positive results.

4.5 Copper Sulphate

Although copper sulphate has been used quite effectively for controlling marine bifouling at Florida Power and Light Company, the Environmental Regulatory Agency, USA has now forbidden the use of copper sulphate and such other toxic materials. According to this agency such materials have adverse effects on marine ecology, plants and marine life and ultimately human beings.This fact has yet to be substantiated by research findings. Copper Sulphate is expensive to use as compared with chlorine. Also the effect on marine environment at the hot discharge end of the used cooling water can be more determimental.

4.6 Mechanical Cleaning

Quite a considerable number of power plants in the world use mechanical cleaning, especially of pipelines off and on, besides using other measures of controlling marine bifouling. With intermittent chlorination, mechanical cleaning is more or less now used as general practice. Russians experts at the Pakistan Steel Mill also recommend the use of mechanical cleaning of pipelines. There are, however, certain coastal installations where this method has not been used. For example, no mechanical cleaning is necessary at the Edison Power Plant which only use that shock system. Fawley Power Plant, UK, have resorted to a continuous dosage of chlorination combined with a velocity of 6 to 7 feet per second.

Manual labour using bars, chisels and water jets have so far been used for mechanical cleaning of pipes. Engineers of Florida Light and Power Company have recently suggested that new devices for this purpose are also currently in use.

4.7 Combination of Chlorination and Heat Shock Treatment

The Southern California Edison Company (1) suggests the use of a double intake in several coastal plants. They suggest the use of intake and discharge

canals alternatively. What is done is that every five weeks canals are reversed at a temperature of 120°F for one hour. Since mussels are sensitive to heat, either they get destroyed or in an attempt to find a new place get washed out in the sea. It may be noted that mussels do not get killed by heat treatment only, so intermittent chlorination is also needed at the plants.

The Karachi Steel Mill in which sea water shall be used for cooling is also anticipating marine bifouling in view of the existing high temperatures. It is also reported that KANUPP is already facing such problems for which research is underway at the Institute of Marine Biology, University of Karachi. A combination of chlorination and heat shock treatment can be suggested for the Karachi Steel Mill Sea Water Supply System.

4.8 Combination of chlorination and high velocity

At quite a few places a combination of chlorination and high velocities have been found to be used effectively. For example, marine growths occur in pipelines or conduits from the pump house to the condensers. At Fawley Power Station in Southampton, UK, considerable marine bifouling is visible on the concrete walls of the channel leading to the pump house. Chlorination is introduced at the rate of 1 ppm just upstream of the trash-racks from mid April to the end of October. In the winter the rate is 2 ppm of 1 hour in each 8 hours. This has been combined with a velocity of 2 meters per second in about 200 feet long conduits from the pump house to the condensers. This combination of chlorination and velocities has taken care of the marine bifouling, but high velocity itself would not have been enough to take care of the problem. This is so in case of the Oyster Creek Power Plant at New Jersey, USA, where the velocity in the tunnel is 10 to 12 feet per second. Despite this velocity 6 to 7 inches growth of barnacles was observed, with the net result that chlorine is also introduced in the water just above the condensers to control slime formation.

At the Port Everglades Power Station in Florida, marine growth including barnacles and mussels has been observed. These fouling organisms have become immune to low doses of chlorine. Higher doses cannot be given because of environmental regulations. Toxic paints were tried with positive results for first six months only. The management has finally resorted to mechanical cleaning.

5.0 SUGGESTED MARINE BIFOULING CONTROLS AND MEASURES FOR KARACHI STEEL MILL SEA WATER SYSTEM

The Karachi Steel Mill Sea Water Pumping plant shall pump sea water for cooling requirements of the thermal power stations, rolling mills, refrigeration plant, slag granulation plant, scrap balling yard, and for refractories production. This plant shall be located near the Steel Mill boundary and water shall enter through an intake located on the Gharo Creek low water line, 3.6 km away. The pumping plant will consist of six centrifugal motor driven vertical type pumps. The pumping plant forebay will have trashracks, trashrake and travelling water screens.

It is anticipated that this plant will also be threatened by marine organisms growth like other coastal installations. As mentioned earlier, due to the absence of enough literature on this problem, the National Engineering Services (Pakistan) Limited carried out a survey of the latest procedures adopted to control marine bifouling at various coastal installations in the world. After taking into consideration the reasons leading to marine bifouling of the Karachi Nuclear Power Plant and taking into consideration the severity and magnitude of the problem and the fact that long pipelines are to be used, a conclusion has been reached that a combination of heat shock treatment and chlorination may be a way out of the problem. Heat shock treatment is necessary to clean the system of any marine growths which may defy chlorination.

5.1 Various methods of chlorination

Following are the various methods by which chlo-

rination of sea water can be done using different methods of injection:

i) Liquid chlorine
ii) Electrochlorinators
iii) A combination of Dual Gas Liquid chlorine and Electro-chlorinators
iv) Hypochlorite

i) Use of Liquid Chlorine

The first possibility in this case is to buy liquid chlorine from the sources available within the country. A survey was carried out for this purpose. Information was obtained regarding the existing chemical industry manufacturing chlorine within the country.

According to the latest information provided by Federal Chemical and Ceramics Corporation Limited, daily chlorine production in Pakistan is 120 tons. This quantity is negligible as compared with 28,276 tons per day production in early seventies of US, 69.2 percent of which is produced by diaphragm cells, 27.6 percent by mercury cells, and 3.2 percent by fuged salt and non-electrolytic processes.

At Karachi, liquid chlorine is mainly manufactured at Arokey PVC Pipe Factory with an output of 4,000 tons per annum.The chlorine is produced by electrolysis and merqury cells of Shinetsue, Japanese make are used. They have plans for extending their current production but it is doubtful if they have any chlorine to spare besides their own consumption.

Ittehad Chemicals Limited, Kalashah Kaku, presently manufacture 80-81 tons of chlorine per day as a by-product in caustic soda manufacturing process. Presently, this chlorine is supplied in small quantities to LDA,KDA, CDA, Pindi, WAPDA, Packages Limited and Defence Units in the country and a little quantity is

also exported to Middle East. In general, about 17 tons of chlorine is put to use and rest is thrown in the nearby nullah. This plant shall be able to increase caustic soda production by 1979 and shall manufacture 105 tons per day of chlorine. Enough chlorine can be spared for steel mill requirements. The only problems faced would be the transportation of chlorine from Kalashah Kaku to Karachi. One way to transport is in cylinders of 900-1000 kg and each truck can carry upto five cylinders. Built-in Storage has to be developed at Karachi so that enough chlorine is available for use at Karachi Steel Mill.

Some other plants in Pakistan also manufacture chlorine as by-product. Adamjee Plant at Nowshehra manufactures 15 tons of chlorine per day for their own consumption. Sind Alkalis, Charsadda Paper Mills, Packages Limited also manufacture chlorine but in small quantities.

ii) Electrochlorination

By generating nascent chlorine through Electrochlorinators from sea water, which contains chlorine at a density of 15,000 to 20,000 ppm, the chlorine is injected into the sea water. Greater efficiency is obtained in this system at the cost of higher costs and the main burden on the cost is because of high consumption of power which is estimated for Karachi Steel Mill to be around 6 kw per kg. of chlorine produced. The main problem here would be the disposal of large quantities of caustic soda which would be manufactured as by-product.

iii) A combination of Dual Gas Liquid Chlorine plus Electrochlorinators

This combination of liquid chlorine from Kalashah Kaku and electrochlorinators to provide at least one day's total backup storage

to cover failure of chlorine, is also one possibility. This unit is capable of shock dose and also can built up the storage slowly. First costs and operational costs are high. Although the system caters for the drawbacks of alternative 1 but faces the problems of alternative 2 above.

iv) Hypochlorite

Certain coastal installations in the world use hypochlorite instead of chlorine because of later's dangerous characteristics. Chlorine is war gas and is difficult to store and use. Anhydrous liquid chlorine has very high thermal co-efficient of expansion and with moderate rise in temperature may cause hydrostatic rupture of tank.Hypochlorite is produced when nascent chlorine reacts with water. In this case the only drawback is that quantity of hypochlorite produced is three times to that of liquid chlorine. At Kutler Power Station in Florida, U.K., marine bifouling is controlled by introducing calcium hypochlorite in powder form into the pump sumps intermittently with positive results.

5.2 Economics of various methods of chlorination

The salient features of economic comparison which was carried of various alternatives for chlorination of Karachi Sea Water pumping plant have been summarized below:

a) for liquid chlorine injection, initial cost of equipment is low, the only high cost being that of operation mainly because of transportation burden. Operational costs have been calculated to be Rupees 2.53 million and capital cost Rupees 1.87 million. The equipment would last for ten years and replacement of parts would be around two percent per annum of capital cost,

b) in the case of electrochlorinator the capital costs are high. With the plant life useful for five years, the running cost is Rs.4.06 million yearly, on the basis of power consumption of 6 kw per kg. of chlorine production,

c) for dual gas system, annual running costs is Rs.3.27 million and capital costs Rs. 3.68 million,

d) in case of hypochlorite system, running cost annually is Rs.8.79 million and capital costs annually Rs.14.0 million.

For the analysis, it can be seen that case (a) is economical for installation and operation. Chlorine which is being wasted at Kalashah Kaku shall be put to good use. It may also be possible to use about eighty percent components of this system, even if later on electrochlorinators are installed.

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