Industrial Waste Pollution

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In natural surface waters, inorganic elements and organic compounds are found in varying degrees of concentration. The natural aquatic environment considered here is defined as containing relatively low concentrations of organic substances and as being aerobic. In such environments the prime movers in biodegradation processes are the saprophytic bacteria. They utilize organic materials as food in their normal metabolic functions. Part of the organic material is broken down into simpler forms that are used as building blocks for cellular growth and reproduction. Another part is oxidized to provide energy for cell synthesis, locomotion, etc. In any real biological system there is a third organic fraction consisting of fragments of compounds originally present which are also broken down more slowly. Thus, inorganic and organic materials serve useful purposes in most surface waters by aiding in the support of the aquatic life.

In most surface waters, and the Chesapeake Bay is not an exception, there is a variety of aquatic life present. Under normal influences, the food chains that have developed in the Chesapeake Bay system have developed in response to evolutionary adaptation involving relatively long periods of time acting in concert with the dilute nature of the aquatic medium. Hence, the nature and extent of elemental and organic compounds of the Chesapeake Bay have critical limitations special to the resident and transient organisms that reside within the Bay and its tributaries. Within certain limits, however, some exposure of the aquatic organisms residing in the Bay to relatively higher concentrations of both organic and inorganic materials may not be detrimental and may even stimulate biological activities in a favorable way.

On the other hand, the occurrence of particular kinds of organic matter may adversely affect beneficial water uses. Organic substrates may deplete oxygen, impart color, produce foams, produce toxic conditions, or result in objectional tastes and odors, as well as inhibit penetration of light through the phototrophic zone. What becomes significant, then, is the type and concentration of the various polluting materials in relation to their effects on water quality and, especially, on aquatic life.

Natural surface waters comprise a dynamic environment. The smallest forms of life, the bacteria, serve as the first links in the aquatic food chain, and they are capable of utilizing most organic compounds as food. In their metabolic processes the original substances are altered (biodegraded) forming intermediate compounds. These compounds may ultimately be degraded to carbon dioxide and water. The intermediate chemicals which are created by such biodegradation at the bacterial level may behave much differently in the aquatic environment than the parent compounds. It becomes obvious then that the study of the behavior of organic chemicals in the aquatic environment involves a highly complex system. It should also be apparent that the subject should be treated systematically and comprehensively within the next few decades if we are to maintain, and indeed enhance the multiple use of the Chesapeake Bay under all the various influences to which it is likely to be subjected.

General sources or organic matter entering the Chesapeake Bay are:
(1) Surface runoff from cities and towns located within its drainage
(2) Industrial waste waters
(3) Treated and untreated domestic sewage
(4) Metabolic byproducts of aquatic life, including the products of bacterial biodegradation.
All four sources contribute significantly to the total organic load received by the Chesapeake Bay waters.

CHARACTERISTICS OF INDUSTRIAL WASTES

Broadly speaking there are four general classes of inorganic and organic contaminants that could be considered to be industrial wastes.

Inorganic Chemical Wastes

Metals such as copper, zinc, chromium, and others are discharged from industrial sources quite routinely in various valence states. The fate of both stable and radioisotopes of these elements in estuarine waters can influence their ultimate disposition in the Bay and thus their biological influences. Bioconcentration of relatively low levels of these elements to many times the concentrations found in water have been reported commonly for benthic filter-feeding invertebrates. Organo-metallic complexes have been shown, in the case of mercury, to affect their toxicity in a way that is not clearly understood at the present time. The chemical chelation of such metals by naturally occurring organic substances can facilitate food chain concentrations of such substances. These food chains must be understood in more detail.

Numerous inorganic ions and compounds are commonly discharged (Na, SO_4, NaCl, K, and others) and they appear to ecologically influence the salinity locally. Estuaries, such as the Chesapeake Bay, can assimilate such ions quite readily without serious impact upon the biota of the Bay if the point of introduction and method of introduction are regulated.

Other inorganic materials such as the rare Earth elements are found only in trace quantities in the Bay's waters, and they should not be allowed to discharge in high concentrations into the Bay. The author has noted that some of the fishes found in the Chesapeake Bay respond rather quickly to such elements, and thus removal of these elements to levels approaching ambient levels must be required.

Nutrient materials such as nitrogen and phosphorus can be found in industrial discharges. Compounds of ammonia are not uncommon. The biostimulatory effect on phytoplankton can produce nuisance conditions locally that might require regulatory action. A later paper will discuss in more detail the ecological implications of such nutrient discharges.

Potential synergistic reactions of substances discharged from separate industrial outfalls have, in the past, produced toxic conditions in surface waters. Ammonium and copper have such potential synergistic action (from a toxicity point of view) and there are numerous other inorganic ionic complexes that behave in a similar way.

Naturally Occurring Organic Wastes

A second category of industrial pollutants involves naturally occurring organic wastes. This category would include those wastes from food-processing industries, paper and pulp industries, petroleum products, and the like. This category represents those organic compounds which are normally found and in which there is a relatively large technology existent involving the biodegradation and industrial waste treatment.

Synthetic Organic Wastes (Exotics)

A third category involves synthetic organic wastes. These unnatural exotics include categories such as biocides, the familiar pesticides and herbicides, and their byproducts, including the waste products of their formulation. Significantly many of these exotics can be altered in such a way that the altered form is more toxic or more damaging to natural aquatic life than the parent compound. Other organic compounds which are produced in rather high volume and exposed to surface waters include various organic plasticizers, detergents, and an almost infinite number of complex compounds similar to the materials listed above. Their impact involves one of relatively reluctant biodegradation and, of course, potential toxic influences upon aquatic organisms.

Thermal Effluents

A fourth category involves thermal effluents produced as a result of cooling waters used in industrial processes and, of course, in the condensation of steam in electric generating facilities. Less data are available to predict precisely the local ecological impact of relatively large electrical generating facilities within complex estuaries like the Chesapeake Bay.

Obviously considerable value is gained through thoughtful siting, construction, and operation of industrial operations which typically require considerable quantities of cooling waters for their operation. Experience within the Chesapeake Bay system has emphasized the need for careful use of biocides within the cooling water system. Moreover numerous scientists have demonstrated the fact that there is a highly important relationship between the amplitude of temperature rise above ambient temperatures (ΔT) and duration of exposure to this ΔT which will, in no small way, determine the ultimate biological impact of thermal effluents within the Chesapeake Bay system. Thus the ecological impact of thermal power plants is a highly specific and individual question involving very complex interrelationships which must be taken into consideration early in siting and design of such facilities.

Because of the ecological uncertainties of plankton entrainment into cooling water systems, as well as the hydraulic entrapment of fish into intake structures, there remains considerable question whether the condenser systems of such plants should be designed for the relatively low temperature rise (5-10° C) and high volumes (up to 5000 CFS) or whether higher temperature rises and subsequently less water is the ecologically preferred system. Obviously no general set of criteria (thermal and cooling water volume limits) will serve under all hydraulic and ecological conditions in systems as diverse as the Chesapeake Bay. Thus, the ecological impact of a thermal power plant (or a system of power plants) will be a highly specific and interrelated question sufficient to challenge aquatic scientists and engineers alike in reconciling the need to maintain systems like the Chesapeake Bay within the range of their ambient thermal fluctuations including seasonal thermal diversity.

One of the most effective ways to achieve control of any of the above waste categories is the requirement that detailed material balance inventories of ingredients, products, and waste compositions be supplied to regulatory agencies for their use in protecting the Chesapeake Bay from uncontrolled release of industrial byproducts. The form of this data could, for example, be in terms of pounds waste per thousand pounds of product per day. Such information has not in the past generally been used either by individual industries or by regulatory personnel to account for the substances discharged or lost from the separate or mixed formulation processes typical of any industry. This information is needed if the control of emission rates into the environment is to be achieved.

EFFLUENT EVALUATION TECHNIQUES

It is quite obvious that no single parameter is sufficient to express the potential pollution characteristics of an industrial waste in the aquatic environment. Rather, several are needed if a reasonable estimate is to be made.

Important considerations in the preliminary evaluation of organic and inorganic chemicals include their structure, composition, and chemical properties. For example, straight chain, branching, ring structure, etc.; and their chemical composition, for instance, the elements and grouping, their redox state, carbon content, and various properties such as solubility in water, volatility and density are important in planning laboratory phases of effluent evaluation. Insight as to the biodegradability in chemical and biological waste treatment systems and their toxicity and biostimulatory influences upon aquatic organisms must be known prior to their discharge into the Chesapeake Bay or its tributaries.

Various laboratory techniques reported in the literature have been designed to measure and predict, to a degree, what the fate and effects of organic compounds will be in the aquatic environment. These techniques normally confine the problem to a manageable number of variables while retaining as many as possible of the important factors of the natural environment being simulated. These factors are so numerous and their influences so interwoven that model systems used in the laboratory are necessarily limited. However, despite the shortcomings, through continued effort and experience, it has been possible to derive information that can be extrapolated and used in predicting the impact of inorganic and organic wastes into natural systems such as the Chesapeake Bay.

OXYGEN UPTAKE STUDIES

Without a doubt free oxygen is one of the most important elements in the aquatic environment for the support of aquatic life. It is soluble in water only to a limited degree, less than 10 milligrams per liter at normal surface water temperatures. When available, dissolved oxygen is used by bacteria and other micro-organisms in the oxidation or stabilization of organic material in water. High organic loads on the aquatic environment may stimulate the organisms to such a degree that oxygen is removed from the water faster than it is replaced from the atmosphere or by photosynthesis. When this condition develops, another group of micro-organisms tends to predominate. These bacteria can utilize materials other than oxygen as hydrogen acceptors and thereby partially degrade the organic material. However instead of innocuous byproducts of aerobic oxidation (carbon dioxide and water) that occur in the presence of free-dissolved oxygen, the degradation from anaerobic bacterial action usually results in the production of relatively energy-rich intermediate compounds, some of which can be toxic to aquatic life, and all of which require ultimate oxidation.

In essence the biochemical oxygen demand (BOD) test consists of measuring the depletion of dissolved oxygen in a sample during or after a period of incubation, five days being used as a standard interval of time. The dissolved oxygen level is usually measured by either chemical methods, such as the Winkler method, or by the use of oxygen-sensitive electrodes.

The results of the BOD test are normally expressed in terms of oxygen. The depletion occurring in five days is considered to be due to the stabilization of carbonaceous rather than nitrogenous materials. The five-day depletion is generally more than half of the twenty-day or ultimate BOD (ref. 1).

Manometric respirometer techniques provide another means of assessing the biodegradability of organic materials. While BOD values can be obtained from respirometer data, the usual applications are somewhat different than those of dilution bottle techniques mentioned above. The higher level of activity of the respirometer flasks more nearly simulates a biological treatment unit than a natural-surface water body.

Results of respirometer studies may also be expressed in terms of oxygen uptake and are usually in the form of continuous records rather than cumulative depletion, depending upon the frequency of data collection. These techniques are especially well suited for rate studies involving oxygen demand.

The chemical oxygen demand (COD) test is designed to provide a measure of the organic content of a sample more rapidly than the BOD test. It can also be used with highly toxic samples. Like the BOD test it can be used with both single component (pure) and multiple component (mixed) samples.

The COD procedure consists of reacting the sample with potassium dichromate under acidic conditions at boiling temperature. Reflux condensers are used to provide the escape of volatile components of the sample. The oxidant is present in excess and the amount consumed is determined by back titration with a reducing agent. Catalysts are required for certain classes of compounds (ref. 1). Chloride concentrations have been reported to interfere with this analysis (ref. 2).

The Total Carbon Analyzer is an instrument that provides a very rapid and accurate method of measuring the total carbon concentration in an aqueous sample and it shows much promise for many areas such as waste treatment and ecological impact studies. In the operation of the instrument a sample of between 20 and 40 microliters in volume is injected into a stream of oxygen gas in a furnace heated to 950° C. A catalyst is present to ensure complete oxidation. All of the carbon in the sample is converted to carbon dioxide and the steam which is created is condensed and removed. The oxygen-carbon dioxide gas stream passes on through a non-dispersive infrared analyzer which is sensitive to carbon dioxide. Results in terms of CO_2 levels are recorded commonly on strip chart recorders. The peak height of such charts is proportional to the original amount of carbon in the sample. Equipped with automatic sampling devices, the carbon analyzer has been used quite advantageously to monitor industrial waste water streams (ref. 3). There seem to be very few compounds which do not react completely in this combustion apparatus.

BIODEGRADABILITY TREATMENT STUDIES

Many types of laboratory scale models and pilot plants have been developed to evaluate the treatability of waste

waters. They are readily adaptable to studies with organic chemicals to determine whether and to what degree these materials might pass through a treatment plant and reach an aquatic environment such as the Chesapeake Bay. The models of all forms of biodegradability treatment systems have been developed for laboratory use and incorporate features of the activated-sludge biological waste-treatment process.

These studies of biodegradability have been very useful in predicting the behavior of organic chemicals in traditional waste water treatment systems. Studies of the reaction rates which influence the time needed for biological waste treatment and, ultimately, the size of the waste treatment system needed have been used to predict whether the waste treatment system can be designed. Moreover, predictions relative to the nature of the biological flock produced and its removal from waste waters through settling can be useful in preventing the discharge of organics into natural surface waters. In essence four general biodegradability patterns have been reported to occur as a result of exposure to organic chemicals. *A first type* involves material which is readily susceptible to biochemical oxidation. *A second type* exhibits the pattern of very slow oxidation involving, presumably, bacterial acclimation to the organic carbon source. *A third type* shows rapid oxidation only after a considerable lag period, again involving very long and specialized bacterial acclimation phenomena. *A fourth type* illustrates toxicity at the bacterial level in which no biochemical attack of the organic compound is measurable.

TOXICITY BIOASSAY EVALUATION

The most appropriate animal for toxicity studies in the aquatic environment is probably the fish, although considerable work has been done by some other author, with crustaceans and insects. Fish serve as very sensitive and subtle analytical tools in studying the effects of various inorganic and organic materials in surface waters. The character as well as the degree of toxic effects can often be observed and thus the ecological impact can be approximated.

Basically the toxicity bioassay involves exposing the test animal to various concentrations of substances of interest for a given period of time. For fish the period is usually one to four days. Standardized procedures have been developed for controlling dissolved oxygen levels, pH, temperature, and the concentration of the test materials (ref. 4). Fish size, age, and history are additional factors which must be considered. Selection of appropriate species and the dilution water depends upon local conditions and the purpose of the bioassay. The type of information which may be obtained from fish bioassay studies are many and varied. The most common is the median tolerance limit (TLM), that concentration at which half of the specimens die in a given exposure period. This is very similar to the LD50 value. This value is more readily determined, but probably of less interest than the minimal concentration which causes death or permanent damage upon long term exposure. Changes in the behavior of the specimens prior to death may provide important information. Studies of fish flesh tainting and influences upon reproductive success are equally important.

Fish bioassay data are in common use today throughout the nation although it has been found worthwhile to have such tests performed by experienced laboratory personnel rather than as a routine monitoring parameter. While some special equipment is necessary, the real problems arise in maintaining the specimens in healthy, normal condition prior to and during the test. Secondary losses of the test compound through evaporation, adsorption, and biodegradation must be prevented or controlled for the period of the bioassay. Environmental factors such as pH, temperature, dissolved oxygen, and sudden changes in other factors such as photoperiods, etc., have a significant influence on the test results. Bioassays generally yield relative rather than absolute results. Some chemicals are proportionally more toxic when in combination than when alone so that synergistic influences must be fully evaluated. Great care must be exercised in extrapolating bioassay results from the laboratory to the field because of the large number of important factors, of which I have only mentioned a few.

BIOSTIMULATION

Though an enormous amount of effort has been expended on bioassay work in this area, very little of this work is directly applicable to the assessment of industrial wastes in receiving waters, the design of waste treatment systems, or to waste management. The complexity of the response of algae to the variety of macronutrients and micronutrients has

severely limited the development of a rational model for predictive purposes using the biostimulation studies.

The biostimulation test usually employed, the batch culture test, is, unfortunately, proving to be inadequate to give more than qualitative results and even these results are very difficult to interpret. The continuous culture bioassay is a more applicable test for receiving waters, yet the relation between laboratory results and in situ response has not been fully established.

Like toxicity this test should also be correlated with the total ecosystem response, especially since the response it is measuring (productivity) is the primary source of food for ecosystems. Once this is accomplished the test will have relevance for ascertaining the effects of waste discharges into coastal waters, and some quantitative relation can possibly be made between the laboratory tests and the system response for use as a waste disposal guideline.

ECOLOGICAL BEHAVIOR OF INDUSTRIAL WASTES IN SURFACE WATERS

Surface Film Phenomena

Surface materials are found in the form of films, lenses, scums, foams, and particulate matter or detritus. Particulate matter may be found associated with film or with scum or foam, or with all of these materials. To a certain extent small quantities of all these materials can be found in all coastal waters and estuaries. Oceanographers have long been aware of the formation of natural sea slicks on the oceans and in the coastal zones and estuaries. Generally the source of surface sea slicks is considered to be planktonic in origin arising from oils produced in plankton blooms which are released when the plankton die. Planktonic oil slicks are a quite common phenomena of tidal estuaries such as the Chesapeake Bay.

Investigations of the surface materials of waste origin have been rare. In recent years numerous investigators have reported the presence of foams, oils, floating debris, and surface organic films and sludges carried by the wind to beaches and shore areas. The identification of the source of surface slicks and films is, with the exception of oil spills, a rather poorly developed science. Generally only crude oil is spilled accidently and in massive quantities as evidenced by the Torrey Canyon, Ocean Eagle, and recently the Santa Barbara Channel incidents. Unfortunately crude oil is generally a complex mixture of hydrocarbons and other substances, some being highly volatile, which makes a meaningful analysis of the properties of the material rather difficult. Review of recent literature suggests that the results of these spills have produced, for the most part, a material which is relatively non-spreading and, in most cases, limited to the surface only. Experience gained in response to these large-scale oil spill incidents suggests that surface containment through skimming and containing structures is the most appropriate method for handling such spills. Attempts to emulsify or homoganize spills into the open water column have proved, in most cases, to aggravate the biological impact of such incidents. The loss of the lighter hydrocarbons, such as the gasoline, results in the build-up of the heavier tars and asphalts which tend to agglomerate and either are carried into beach areas or sink to benthic layers with relatively poorly described ultimate impact on the benthos. Discharge of municipal and industrial wastes into estuarine and coastal waters without skimming and removal of floatage has, in the past, proven to be a rather poor water management practice. Moreover bacterial counts taken from beach sands and waters located on the Pacific and Atlantic coasts have shown bacterial counts to be relatively high and directly related to tidal movements of sewage outfall plumes of both industrial and municipal origin.

Aside from the concentration of microbial populations adsorbed onto suspended particles of the water column as well as the surfaces of the bottom and shore zones, the surface film of water has been shown in some instances to concentrate larger bacterial populations per unit volume than the underlying water. Zobell (ref. 5) has explained such bacterial accumulations to be a result of the following:

(1) Surface tension of the film itself

(2) Low specific gravity of bacteria

(3) The buoyancy of lipids and gases associated directly or indirectly with bacteria

The surfaces of coastal waters are involved in biological stabilization of wastes (however dilute they may be) through the influences of four major natural phenomena (ref. 6). These are:

(1) Bacteria tend to concentrate in the surface film.

(2) The film moves with wind currents at speeds in excess of measured ocean current.

(3) Internal waves, winds, and currents cause horizontal compaction and concentration of materials in the surface film.

(4) Dispersion or diffusion of those surface film materials in underlying water appears to be surprisingly small.

Interfacial Phenomena

This general category includes a vast number of different phenomena. Some of these are liquids and liquid emulsions; the selected adsorption of organic and inorganic nutrient substances on gas, liquid, and solid interfaces; flocculation and sedimentation of suspended matter at the location where saline water encounters fresh water in estuaries, typically in the middle part of the estuary; and the effects of deposition of digested sludge on the bottom of the estuary or coastal zone. The basic principles underlying most of the surface reactions taking place in the liquid bulk differ only in complexity from those described above for surface films. But water circulation and suspension of the film complicate the phenomena considerably. Most of the waste waters from large municipal and industrial outfalls are weak suspensions and solutions of both inorganic and organic materials. Natural surface waters are extremely dilute solutions of inorganic salts, atmospheric gases, and extracted organic materials. Under most conditions these two types of solutions mix and react slowly over relatively long periods. Significantly the biological organisms that live in estuaries such as the Chesapeake Bay are adapted to these relatively low concentrations and commonly react adversely to both sudden and long term discharges of both treated and untreated waste substances.

Emphasis on the relatively dilute nature of most waste streams is made primarily because of the need to recognize the inherent difficulty of treating both domestic and industrial waste effluents so as to produce completely clarified and purified solutions. Under even the best conditions of current and foreseeable design and operation procedures, we will be required to disperse treated waste waters from our most heavily populated areas into surface waters, most of which will ultimately mix with estuaries such as the Chesapeake Bay. My point is that because of the volumes involved and the relatively dilute nature of both the waste streams and coastal waters, we should consider the physical, chemical, and biological processes that occur when such solutions ultimately mix. With regard to the subject of this paper, the major biological processes which are involved with waste stabilization are bacterial fermentations which occur on interfacial surfaces. Exploitation of such processes is the major mechanism of waste stabilization with conventional biological waste treatment systems and, on a somewhat reduced scale, in all nonsterile solutions of water.

Recall that during the conventional biological waste treatment the waste waters are distributed over large surfaces. This occurs when soil, sand, and gravel beds are irrigated and when beds of stones are intermittently flooded. We use intermittent flooding and controlled spray distribution to secure ventilation and adequate oxygen supply for the large BOD resulting from bacterial fermentations at the surfaces. In doing so we also provide additional air-water surfaces and it has been repeatedly noted that these air-water interfaces concentrate organic materials from solution. Large organic capturing surfaces are also produced by entrained air bubbles in the great variety of biological aeration treatments that have been developed. Of significance is that surfaces do capture materials that tend to depress the interfacial tension of solutions and colloidal suspensions, including nearly all types of soluble organic wastes and very fine organic solids. Of course, such simple physical surfaces become saturated after the irrigant comes to equilibrium with the interfacial film with relatively little net change with time. It is at this point that biologically active surfaces become important in the natural biodegradation of wastes introduced into surface waters.

Largely as a result of observations of Zobell and his colleagues in the 1930's, we can predict that marine bacteria and other micro-organisms are concentrated in direct proportion to the surface area available for such adsorptive phenomena. Bacterial cells approach colloidal dimensions, and the physical systems that favor concentrations of organic molecules at interfaces also favor concentration of organic molecules in the micron and submicron size range, especially when the solution suspensions are weak, as is the situation with well-mixed waste discharges in coastal waters. Observation of emergent vegetation along the shores of all surface waters reveals a microhabitat for such micro-organisms on nearly any submerged or partially submerged object. Examination of the relatively thick films of micro-organisms that actually appear on such submerged surfaces reveals that such growths are commonly a millimeter thick, especially in mixing zones from discharged wastes, and the mass of living material in them is much greater than

might be anticipated at surfaces wetted with weak organic colloidal suspension. Very clearly surfaces actually favor the growth of micro-organisms and this growth sticks to the surfaces. These films are essential for the biodegradation of organics introduced into coastal waters and they serve to continuously oxidize organics while renewing themselves. These biological surfaces adsorb and temporarily store organic solutes which are available for oxidation by the cells of the film for the yield of energy necessary for the formation of new cells. From a bioenergetics point of view such energy exchanges are extremely inefficient and it has been observed that less than one percent of original organic matter is converted to cellular material.

Biological films within the water column perform with high efficiency the job of energy degradation and commonly can be shown to contain many types of bacteria. Mixed populations oxidize organic wastes more efficiently than single species, and an effective population will contain groups that oxidize the fermentation products of primary species. Protozoa, rotifer, worms, snails, and many high taxa are able to feed on the bacterial film with high efficiency especially in the shore areas of estuaries that contain submerged vegetation and substrates. The transfer of material and energy from one predatory species to another looses energy and carbon dioxide from the aquatic ecosystem, and the total energy removal by such a complex society of aquatic organisms is always higher than that of a less diverse group.

It is important to realize that interfacial phenomena involving biological films will also be expected to occur on all surfaces of suspended solids entrained in waste water and coastal water mixing areas prior to their settling out of solution. Also, any tidal or man-influenced turbulence will tend to resuspend flocculated organic and inorganic materials and thus aid in the maintenance of relatively large reactive surface areas for the biodegradation of fermentable wastes. Planktonic organisms, such as diatoms, have also been observed to provide excellent surface substrates for bacteria concentration and thus appear to be involved in the process of biological stabilization within the water column.

It should be noted that marine bacteria, fungi, actinomyces, and other micro-organisms can utilize a wide variety of organic and inorganic materials as food, provided that it has available energy. As noted above, some waste discharges from both municipal and industrial discharges contain some organic substances that do not occur in nature. Experience with biological waste treatment has shown that many of these materials can be biodegraded by micro-organisms, but it is not possible at this time to predict that a given material will be attacked by looking at its chemical formula. Bacteria are highly adaptable with time to even the most complicated organic structures, providing that other more easily biodegradable and energy-providing substrates are not available. Problems occur largely because of this inherent preference of bacterial populations for the more energy-rich and fermentable domestic organics over more complex and chemically elegant materials often discharged in low concentrations into estuaries such as the Chesapeake Bay.

Settling of flocculated and adsorbed organics does occur in time and benthic accumulation of such organic debris ultimately occurs. Both aerobic and anerobic biological stabilization of introduced waste organics and the cellular debris of organisms residing in the water column above is known to occur in the bottom layers of estuarine and coastal waters. Provided that preliminary treatment of discharged wastes has occured (skimming, screening, primary settling) benthic loads of fermentable waste should not exceed the assimilative capacity of these layers. Experience with inorganic waste substances such as metallic wastes, isotopes, pesticides, etc., suggest that benthic filter-feeding organisms, especially annelids and molluscs, are likely to concentrate non-biodegradable substances to many times the levels found in the water. Such benthic invertebrates have adapted to filtering relatively large volumes of highly dilute solutions per day in their straining and filtering processes. In doing so the flocculated organics and organic-inorganic semi-solids that settle to the bottom provide benthic populations with essentially all of their energy and nutrient needs. Excessive deposits of solids have proven to be responsible for the disappearance of this most desirable tropic level in the aquatic ecosystem. Significantly toxic wastes are especially damaging to benthic populations of filter feeders and the relative influence of such waste products is generally poorly understood in natural surface waters.

The role of benthic silts in the biological stabilization of wastes discharged into marine waters appears to be much less than that of waters from which they settled. Marine muds were found by Renn (ref. 7) to strongly adsorb soluble nitrogenous organic waste materials of planktonic origin. Muds were found to exert little, if any, direct effect upon the rates of efficiency of anaerobic bacterial decomposition of the same planktonic materials. The fact that marine muds adsorb nitrogenous organic materials may be significant, however, in determining the normal course of breakdown in benthic layers. Soluble organic matter released by autolytic or digesting processes of benthic invertebrates may also be localized in the mud where anaerobic changes and low temperatures prevail. The adsorption of organic and inorganic materials onto the surfaces of suspended silts from land sources appears, then, to be a major mechanism in the transfer

of waste materials from the open water to benthic layers in estuaries and coastal waters. Such materials are likely to be available to benthic animals and thus require review and study of possible toxic influences upon benthic organisms as well as their incorporation into biological food chains that involve man either directly or indirectly.

Knowledge of the extracellular products of planktonic organisms is exceedingly limited. Although a variety of materials are liberated from rapidly growing algal cells (carbohydrates, fatty acids, amino acids, polypeptides, growth substances, vitamins, enzymes, and antibiotics) we do not at the present time know of the influences of even the most obviously important group, the antibiotics, upon the survival of enteric pathogens that are associated with waste discharges. These pathogens have been repeatedly shown to die off rapidly in sewage oxidation ponds containing abundant algal growth (ref. 8). Such large scale die-offs could be the result of the liberation of large amounts of antibacterial substances during such algal blooms, but field demonstration under natural conditions is yet to be performed. Little is known of the chemical nature of such natural antibiotic substances, but, clearly, research is needed before meaningful appraisals can be made.

Benthic Phenomena

The use of estuaries and coastal zones for the disposal of treated and untreated domestic and industrial sludges has left considerable questions regarding the impact on the benthos. Research currently underway by Pierce and his associates at the Sandy Hook Marine Laboratories has shown that the deposition rates and the growth rates of the sludges on the benthos are more biologically devastating than had been predicted prior to the disposal operation. The potential impact of sludges that contain considerable quantities of toxic materials must be regarded with the utmost concern. Leaching of nutrients contained within such sludges is also of considerable potential impact on estuaries and coastal zones receiving such sludge deposits. Relatively little life has been reported to exist upon these sludge beds and indeed in relatively large areas surrounding the sludge beds. Some possible topics of investigation of these beds over the next few years must include at least the following areas:

(1) The rheological properties of submerged digested properties including the growth of the sludges as a result of continued deposition

(2) The leaching and exchange of materials at the sludge interfaces with the open water column

(3) The rates of decay and change in properties of the submerged sludge

In conclusion, the fate of industrial and domestic wastes, both treated and untreated, which reach the waters of the Chesapeake Bay and its drainage must continue to be of utmost interest to scientists, engineers, and regulatory agencies if we are to keep up with the demand upon the Bay waters for assimilating waste materials. Indiscriminate discharges of industrial wastes must be controlled, and the burden of proof relative to the ultimate effect of the discharged materials upon the Chesapeake Bay, its water, and its populations must rest upon the industrial community. While a great deal of scientific data remain to be collected with regard to the waste-assimilative capacity of an estuary with the proportions of the Chesapeake Bay, the ultimate impact and fate of inorganic and organic industrial waste products within the waters of the Chesapeake Bay can be predicted in a general way through some of the procedures outlined in this paper. This type of information coupled with data regarding the biological populations residing in the Bay and the physical mixing and dispersion mechanisms within the Bay—both subjects which will be covered in later papers—should give the regulatory agencies, concerned citizens, and scientists some of the information they will need to make the management decisions that will be required in the coming years.

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