IN: ENVIRONMENTAL QUALITY: NOW OR NEVER, SIM Special Publication No. 5, E. Lansing, MI: Continuing Educ. Service of Michigan State University, pp. 192-197, 1972.
(SIM = Society for Industrial Microbiology)

INDUSTRIAL WASTES:BIODETERIORATION VS. BIODEGRADATION*

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20th century man is literally hoisted on his own petard – his technology has helped him to design materials that seemingly resist the deteriorating effects of his environment and he is reaping the whirlwind for what he has sown. The need to assess the impact of the accumulation of non-biodegradable materials has led to the development of many innovative processes for their eventual elimination, many of which involve the imaginative use of micro-organisms. There is another side to the coin of biodegradation vs. non-biodegradation. Since the dawn of man's time on this earth, he has been plagued by the effects of biodeterioration, and much effort has gone into finding methods for its prevention. In order to fully appreciate what I mean by the term biodeterioration, I will give you a definition which is accepted by most individuals working in this area of bioscience. Biodeterioration is any undesirable change in the properties and material caused by vital activities of organisms (Hueck, 1968). Perhaps we can settle for this simple definition of biodegradation: The breakdown or utilization of materials by organisms within "a reasonable period of time." A reasonable time depends upon how fast the material accumulates and how damaging it is to the ecology. For example, the recent Torrey Canyon incident off the coast of Great Britain in which thousands of gallons of crude petroleum were dumped into the North Sea, provoked a great deal of discussion on the impact of oil spills on the biological economy of marine environments. Efforts were directed toward making the oil more biodegradable. Individuals were concerned with seeing to it that the oil was assimilated as rapidly as possible without causing undue damage to more sensitive living creatures. If the same oil is transposed into one of several locations, for example, as an emulsion or lubricant in the machine tool industry, individuals in these areas are concerned with minimal biodegradability. In other words, they are interested in preventing deterioration. Where does one strike the happy medium? I have previously stated that biodegradation was utilization of materials within a reasonable period of time. It has been considered

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almost axiomatic that all oxidizable organic compounds would find a host to dine upon them. However, all we need do is look around us to find examples of organic materials that have resisted the ravages of biological predation (Table 1).

TABLE 1

ESTIMATED AGE OF NON-BIODEGRADABLE COMPOUNDS

Material	**Age in Years**
Leather	2000
Humus	more than 34,000
Lignite	1 million
Amber	25 million
Chitin	500 million

Recently much study has gone into finding out the basis for this resistance to biodegradation. Martin Alexander (1963) suggested that we discard the principle of microbial infallibility and replace it with a more rational understanding of what he refers to as molecular recalcitrance. In other words, if we examine the reason why a compound or series of compounds resist microbial attack, it may be possible to overcome these difficulties if the aim is to get rid of these compounds in nature, or it may be possible to design compounds that resist attack in the areas of use thereby preventing deterioration but once discarded proper biological agents and/or environments may be used to inhibit those factors that are responsible for non-biodegradability. Industry will have the dual problem of disposing of non-biodegradables; for example, peach pits from a peach cannery are also biodeteriorables. These latter compounds tend to increase the organic load on the environment, particularly the aquatic environment. The same cannery would have to dispose of damaged fruit, wash water, etc. which would tend to increase this organic load. Both of these are pollutants. Before going into the major portion of this paper which relates to innovations in waste treatment, I would like to give a quasi-official definition of pollution (NAS-NRC, 1966). "Pollution: an undesirable change in the physical, chemical or biological characteristics of our land, air and water that may or will harmfully affect human life or that of other desirable species; our industrial processes, living conditions, and cultural assets, that may as well waste or deteriorate our raw material or resources." Perhaps, just as appropriate an alternative: "a resource out of place."

There are three ways in which industry can solve its waste disposal problems. First, better manufacturing procedures or different procedures which will lead to either more easily disposable wastes or less waste. Second, it may be possible in a number of areas to recycle internally some of the accumulated materials or to utilize the materials internally after making some reclamation. It has been facetiously suggested that one

method of cutting down industrial pollution would be to insist that all users of public water take their influent downstream and discharge their effluent upstream. The third approach and perhaps the most exciting and innovative, is conversion of the waste product to something useful.

Solutions to non-biodegradability problems

One solution that already met with some success has been better molecular design. The change in side chain structure of the Alkyl Benzene Sulfonates has appreciably increased biodegradability. Attempts are also being made to modify the structure of the chlorinated hydrocarbon pesticides in order to reduce their persistence without affecting their usefulness. If change in molecular design is impractical, perhaps finding a new use for discarded materials is an answer. For example, disposable glass ground up with old tires is being tried as an asphalt substitute in road beds.

Food Industry

Recovery of Fish oil and protein – In Japan Kato and Ishikawa (1969) have developed a process from the sizable Japanese fish sausage industry enabling them to profitably convert effluent waste which itself was a pollutant to usable oil and protein. The fish used in these processes were, of course, not fit for anything but this type of operation (e.g., Horse mackerel). Eight volumes of water per weight of fish were needed to make the finished product and the effluent contained 0.5% protein and 0.2% fish cil. In one plant this was the daily equivalent of 25 tons of protein and 1.6 tons of oil from 1170 tons of raw effluent. They succeeded in lowering suspended solids 81% and BOD 77% in their effluent in addition to selling the recovered nutrients: protein (hydrated) 0.6¢/lb., oil 3.5¢/lb.

Spent Coffee Grounds – Since World War II the amount of coffee processed in the "instant" market has increased explosively. As the volume increased, the number of processing plants have decreased. Presently 80 plants are responsible for 98% of the coffee processed. This is equivalent to 500 million lb/yr. The smallest processor used about 5 million lb/yr. Even this plant would have about 1440 tons of dry waste annually. This industry has a dual waste problem. Processing yields a highly colored, high BOD (3000 mg/L) waste water. Until 1960 this was lagooned; now it is used for spray irrigation. Disposal of spent grounds has been handled in three ways: discharging into rivers, as sanitary landfill, incineration (9000 BTU/lb). Bond and Canter (1970) mentioned several approaches to these disposal problems. For example, a patent has been issued for the use of spent grounds as a base exchange water softener; it can remove up to 10.000 gr/cu ft of water hardness. It also has been suggested as an animal feed supplement. However, because of nutritional imbalance, it must be limited to 5% of the total diet. I should mention at this point that at least one major industry, the brewing and fermentation industry, has been able to profitably dispose of spent yeasts as cattle food. Perhaps this additive is responsible for our "contented cows." Spent grounds are being explored as composting material (contains 1.8% N, 0.36% K_2O and 0.13% P_2O_5). When 100 lb. of spent grounds is mixed with 0.25 lb. of 8-8-8 fertilizer and 1 lb. of lime, a humus-like conditioner or potting soil is formed. This mixture yields about 47 lb. of dry compost from the waste of 132 lb. sack of green beans after two weeks of composting.

Machine Tool and Petroleum Industry – For the last 7 or 8 years, several laboratories around the world have been utilizing petroleum for growing microbes as a potential food for protein deficient areas and also as possible animal food supplement. In one ideal situation, *Candida lipolyticus* helps bypass the cracking operation by growing on the higher boiling petroleum fraction, thereby degrading it and leaving the much more desirable gasoil untouched. Although there are several pilot plants producing "petroleum food" no large scale attempts have yet been made for its utilization. However, it has been estimated that 5 tons of beef cattle make only 70 lb. of protein daily while the same amount of yeast can produce 100,000 lb. As our grazing lands shrink and our population expands, we may have to turn to some form of microbial protein as a nutritional supplement. E. O. Bennett of University of Houston has developed a program which combines imagination with ingenuity and suggests a novel way to convert an industrial waste product, spoiled cutting oil emulsion, into high protein microbial fish food (Bennett, 1970). Machine tool coolants used today are primarily oil-in-water emulsions containing 1-10% mineral oil among other things. For a variety of reasons central circulating systems containing up to 100,000 gallons often become rancid. Problems associated with control of spoilage have increased due to restrictions on phenolic germicides, and the amount of oil allowed in effluents (legally as low as 0.5 ppm). Under working conditions, total bacterial counts can reach the billions/ml. Bennett found that there was a 36% conversion of soluble oil to protein in two weeks. The protein content varied from 38-75%. By adding a cheap readily available N source (5000 ppm of early morning male urine), not only was the growth rate of the microbes in the spoiled emulsion increased but also the quality of microbial protein was greatly improved. On a nutritional scale in which milk protein rated 88, beef 84 and chicken 82, protein from two microbial oil isolates rated 83 and 75 respectively. Bennett recommends that pellets of this material be used for fish farming in areas of heavy industry with large bodies of fresh water nearby, e.g., Detroit. In our own laboratory, we have taken another approach to solving the cutting fluid spoilage problem. Since chemical biocides either are not universally successful or legally acceptable, we have

tried at the laboratory level the use of ionizing radiation from Cesium 137 to limit the growth of bacteria in coolants (Rossmoore and Brazin, 1968). Despite the relative success of this technique, its acceptance is still a long way off, the fear of radiation being what it is.

Other Problems – Other Answers – Bigness in today's economy has even reached animal husbandry. Mass rearing of poultry, cattle and swine has reached the level where the concentrated buildup of manure has become a serious disposal problem. For example, Laak (1970) estimates that by 1973, Orange County, Calif. will have only 40 ranches raising one million chickens. The waste equivalent is approximately 10 chickens equal 1 man and 16 men equal one cow (90 lb. wet manure/day). You can envision the disposal problem of a fattening pen containing 10,000 head of cattle (a city of 160,000 people) or a chicken factory with 100,000 chickens (a small city of 10,000). In the "good old days," the farmer had no trouble spreading his own (farm) manure and selling the excess to passersby for 25¢ a bushel. Sad to say, trucking organic fertilizer more than a very few miles is economically unsound, the cost of hauling exceeding its value. What are the answers? The routine treatments used for other kinds of wastes, i.e., lagooning, activated sludge, anaerobic digestion, all of which are costly but necessary, are discussed in detail by Laak. He suggests that the answers lie in controlled nutrition which reduces the amount of manure per animal and the nitrogen content of manure, and in better planning of location for confinement of animals and utilization of manure. Camp (1969) mentions a rather unique approach to reducing the waste in a poultry processing plant. Feather and offal are mixed to form a meal and subsequently added to blood, lungs and fat. A chicken feed meal results that analyses 63% protein, 20% fat and 2% fiber. About 330 lb. of meals is produced from 1000 birds – and the BOD load to the effluent is also reduced!

Phosphate Removal by Algae – Phosphate excesses in waste water, which eventually produce stream and lake excesses, have been targeted as the prime cause of eutrophication. This mineral is considered the limiting nutrient in the growth of certain algal species. Their overgrowth creates the infamous "Algal Bloom" whose subsequent death chokes the lakes. The tables have been turned! Algae have successfully been used in industrial lagoons to remove the phosphate prior to discharge of effluent.

Recycling of Industrial Water – Necessity is the mother of invention! Ten percent of the waste water from West German towns and factories is recycled for public and industrial water supplies. West Germany meets more than 60% of its water demands by recycling waste water within its factories. This is particularly true in the Ruhr where all communities, coal mines and factories are forced to join water purification associations in which financial liabilities for water treatment are assessed on the basis of the amount of pollutants discharged. These penalties plus the very low rainfall of the region have been the incentive for numerous innovations. For example, they have become highly skilled in utilizing river banks for filtering polluted water into infiltration basins. The seepage time varies from 40-100 days depending upon the degree of pollution. The Essen-Uberugh waterworks gets 26,400,000 gallons per day this way. Except for high carbon dioxide content, this water is fit to drink.

I have only touched on the numerous potential solutions to our environmental problems. With money and effort all are amenable to treatment and to paraphrase Hamlet "there are more waste treatment methods on heaven and earth than you've dreamed of."

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