Waste-Water Treatment: The Tide Is Turning

In this age of pollution one of the more encouraging developments is the work that is being done in sewage treatment. Although no massive reductions in water pollution have occurred, there have been a few cases of successful pollution abatement—parts of the Farmington River in Connecticut, the Willamette in Oregon, and Lake Washington in Seattle, for example. The construction of new sewage treatment plants, while not spectacular, has been gaining on the population. From about 1940 until 1962, the number of new facilities just kept abreast with or fell slightly behind population increases. From 1962 to 1968, however, the population served by sewers increased from 60 to 68 percent.

But perhaps the most significant advances have been made in research and development for sewage treatment. Since 1960 the government has put more than $25 million into waste-water treatment studies. A recent article cites 85 processes being studied at more than 150 locations (*1*). Of special interest are three pilot plants operated by the Federal Water Quality Administration (FWQA) and a 7.5 million gallon per day (mgd) advanced treatment plant operated in California by the South Tahoe Public Utility District.

Treatment

About 1.8×10^{11} gallons of water are used in the United States each year to carry wastes from industries, businesses, and homes. After use this vast quantity of sewage is still more than 99.9 percent pure water, but the contaminants cause deterioration in water quality of receiving rivers and lakes.

For treatment purposes, the contaminants generally are considered as groups such as suspended solids, dissolved organics, and dissolved inorganics. Nitrogen and phosphorus are considered separately because of their role in eutrophication. A property of sewage that particularly degrades natural waters is its ability to consume oxygen. A somewhat arbitrary but useful measure of this property is known as biological oxygen demand (BOD).

The sewage from a little less than a quarter of the population of the United States receives only primary treatment. (About a third of the nation's population lives in areas where there are no sewers, and the sewage from about 5 percent of the population receives no treatment.) Primary treatment consists simply of allowing the sewage to settle and separating the water from the sludge at the bottom and the scum on the top. Such treatment removes about a third of the BOD and suspended solids and a few percent of the refactory organic compounds and plant nutrients.

Sewage from about 40 percent of the population gets secondary treatment. The most widely used methods now in operation are the trickling filter and activated sludge processes. In the first process, effluent from primary treatment is allowed to trickle through a deep bed of rocks containing various microorganisms that utilize organic and nutrient materials in the sewage. In the second process, the microorganisms use up primary effluent materials in tanks through which air is passed. Well-operated activated sludge tanks can remove up to 90 percent of the suspended solids and BOD, and good trickling filters remove 80 to 85 percent. In practice, figures closer to 75 percent are more common.

The use of pure oxygen in the activated sludge process has been called the most significant recent advance in sewage treatment. The major capital cost of an activated sludge plant is the buying of land for the tanks, and the major operating expense is forcing compressed air through the waste water (which has a head of 10 to 15 feet). For about 20 years engineers have known that with pure oxygen, more bacteria could be supported in a smaller space and that less pumping would be required; but an economically competitive system in which pure oxygen is used has emerged only within the past 2 years.

The Linde Division of Union Carbide has developed a system in which oxygen is circulated in closed tanks. The system achieves 90 percent utilization of oxygen—as opposed to 5 to 10 percent in conventional systems—and can support more bacteria than the air system.

Last year the process was compared with conventional activated sludge treatment at the 2.5 mgd pilot plant in Batavia, New York. On the basis of this study, Union Carbide says that capital investment savings of 16 to 20 percent and operating savings of up to 50 percent should be possible.

One of the 20 mgd activated sludge tanks in a Brooklyn plant is to be converted to a pure oxygen system and should be in operation by the spring of 1971. If the system fulfills its potential, the Brooklyn plant will be the first of many.

Many sanitary engineers think that in the future physical-chemical methods of secondary treatment will begin to replace the conventional biological methods. In one method being tested on a relatively large scale, lime is added to raw waste water to precipitate phosphates and to hydrolyze the organic compounds. At the FWQA Blue Plains pilot plant (near Washington, D.C.) the method is being tested in a sequence that involves lime precipitation, carbon adsorption columns, and nitrogen removal. The main problems (apart from nitrogen removal) have been lime handling and biological growths on the carbon filtering columns.

The system is being compared directly with a conventional biological treatment scheme, and, during the few months of trial, the physical-chemical process has removed less of the BOD. In spite of the operational difficulties and lower BOD removal, some engineers think that the system is ready for full-scale operation in situations where its advantages—smaller size, better reliability, and efficient phosphorus removal—are needed.

Advanced Waste Treatment

Until a few years ago when it was necessary to reduce the concentration of substances not eliminated in the secondary step, some additional treatment process—generally chemical precipitation or filteration—was tacked on and the process was called tertiary treatment. In the last 10 years, a wide variety of additional treatment steps have been considered, and they can often be introduced at earlier stages of the treatment sequence. An integrated system that includes such steps is called advanced waste treatment (AWT).

Most of the procedures used in AWT

have been adapted from other industrial uses. For example, there are dozens of chemicals that can be used for precipitation and flocculation and as filter aids. Filters are also widely used in industry, and about 20 multimedia filters are being considered for use in waste-water treatment. Microscreens—metal screens with mesh on the order of a few tens of microns or less—are also being tested. Direct comparison of microscreens and filters by the Metropolitan Sanitary District of Chicago has shown that the multimedia filters (sand and coal) remove more carbon. However, there are several advantages of microscreens that make their development desirable. They cost less, are easier to clean by back-washing, and require almost no head (hence reduced pumping costs). They can remove about 50 percent of the BOD and suspended solids, and this kind of performance is adequate in some cases.

For refractory organic compounds, adsorption is required. Most adsorption is now done on granular carbon, but powdered carbon that is in flowing beds or that is added to the effluent can also be used. Powdered carbon requires much less contact time, but it is harder to handle. Both types remove 70 to 80 percent of the dissolved organic compounds.

The feasibility of using columns of granular carbon to completely replace secondary treatment has been demonstrated at the FWQA pilot plant at Pomona, California, and this technique will be used at a 10 mgd plant to be constructed at Rocky River, Ohio. The sequence will be chemical treatment of the raw sewage for settling and phosphorus precipitation, and then passage of the effluent directly to carbon adsorption columns (which in this case will also act as filters).

Granular carbon can be regenerated in multiple hearth furnaces with about 5 percent loss. The best method demonstrated for regeneration of powdered carbon is a sand-bed burner. The 15 percent loss of carbon might be partially due to the small scale of the pilot test. A larger unit is being installed in Salt Lake City.

Nutrients

The role of nitrogen and phosphorus in the eutrophication of lakes and rivers has led to some legislation limiting effluent concentrations of these substances and will undoubtedly lead to more. Secondary biological treatment seldom lowers concentrations sufficiently to meet these standards, so some advanced treatment is necessary.

Scaling from phosphates is an old industrial problem, and the technology for removing it by lime precipitation has long been known. Likewise, regeneration of the lime—especially in the paper industry—has been practiced for many years. Both techniques have been applied more or less successfully to waste-water treatment.

The possibility of phosphate removal by biological methods remains open and is being studied. Activated sludge treatment typically removes about 30 percent of the phosphates in sewage, but in some cases—most notably at a plant in Baltimore—removal of up to 90 percent has been observed. The reason for this is not known. Both biological and chemical explanations have been proposed, and a test of the biological hypothesis is underway at a pilot plant in Manassas, Virginia. An understanding of the fundamental process could lead to a technique for phosphate removal during secondary treatment. This would be very useful in that phosphate removal is often the only advanced treatment needed for many pollution situations.

The methods now being used for nitrogen removal are not very satisfactory. In the ammonia stripping process, ammonia ions are converted to ammonia by raising the *p*H (usually by addition of lime), and the ammonia is driven from solution by vigorous agitation with air. Removal of 90 percent of the ammonia has been reported at Lake Tahoe and at Blue Plains, but in both places there have been problems. Precautions must be taken to prevent scaling, and temperature variations greatly alter the effectiveness of the process.

Methods of removing nitrogen biologically are also being tested at several places. Ammonia in the effluent can be converted to nitrates by biological oxidization. Another type of bacteria converts nitrates to free nitrogen. In this last step it is necessary to provide a source of carbon to the bacteria. Methanol is now used, and the cost of this chemical is the limiting factor in the process.

There are dozens, if not hundreds, of ion-exchange resins available for a variety of uses. Fairly successful removal of ammonia has been achieved with resins at the Blue Plains pilot plant, but the cost of resins is high.

One recent development with much promise is the discovery of a natural mineral zeolite, clinoptilolite, which adsorbs both phosphates and ammonium ions. More research on the reliability of different sources of the mineral, its durability, and methods of regenerating it is needed before it can be known whether this mineral will be suitable for general use.

Demineralization

In some cases it is desirable to reduce the total mineral content of waste water rather than only that of nitrogen and phosphorus compounds. This can be done with ion-exchange resins, by reverse osmosis, or by electrodialysis. All three techniques for water recovery are used in industry, and the last two have been tested for several years as a means of desalting seawater.

In ion exchange positive ions are exchanged with hydrogen ions, and the negative ions are exchanged with hydroxyl ions; the exchanged ions then combine to form water. The resins must be periodically recharged with acids and bases. As was mentioned in connection with nitrogen removal, the cost of ion-exchange resins and of regeneration is high by waste-water treatment standards.

In electrodialysis, an electric current is passed through the solution and the ions collect at the anode and cathode after passing through selective membranes (which are actually ion-exchange resins in sheet form). Brackish water collects in cells at the anode and the cathode, and partially purified water is taken out of the center cell. Organic molecules cannot be removed by this process, and they tend to collect on the membranes and reduce their effectiveness.

In reverse osmosis, water is simply forced through a membrane. One of the main difficulties is supporting large surfaces of the relatively weak membrane so it can withstand the necessary pressure. During the past decade four support schemes have been developed and are being tested. Organic molecules tend to foul these membranes also, but the problem is not so serious as with electrodialysis. Since it is the water, not the ions, that pass through the membrane, reverse osmosis reduces both organic and mineral content of the water.

At the Pomona pilot plant all three methods are used to demineralize the effluent from the same activated sludge-carbon absorption treatment. Typical results for reverse osmosis are 90 percent reduction of total dissolved solids and 75 percent recovery of water; results for ion exchange are also 90 percent reduction but 85 percent recovery; and results for a one-stage electrodialysis unit are about 35 percent reduction and 92 percent recovery. A process with about 35 percent reduction of total dissolved solids is useful, because this is about equal to the amount of solids added to water as the result of human use.

Electrodialysis and reverse osmosis produce large volumes of brackish waste water, and these processes may be practical only in areas where ocean disposal is possible.

Sludge handling is by far the most difficult problem in sewage treatment. The cost of dewatering the sludge and disposing of the solids accounts for 25 to 50 percent of the total cost of treatment, with the higher figure being more common.

After all other treatment is done the plant is left with a mixture of 5 percent hydrophilic colloidal solids suspended in 95 percent water. A wide variety of techniques have been tried to separate this mixture. Chemicals to precipitate, flocculate, hydrolyze, and oxidize have been used; and it has been suggested that an attempt be made to isolate a flocculating agent produced by bacteria that are naturally present in the sludge.

Anaerobic digestion is commonly used. Cooking the sludge under pressure, freezing, radiation, and ultrasound have been tried—with the cooking process showing some promise. Mechanical separation devices include the development of a solid bowl centrifuge, which is now being used, and the design of vibrating screens.

Disposal of the solids by landfill, sale as fertilizer or soil conditioner, and settling of the sludge in lagoons have all been used but will probably decrease as disposal by incineration increases.

Again, a fundamental knowledge of the process might lead to a major new method of treatment. Some chemical or physical system capable of breaking up the colloidal system that so tenaciously holds the water would be the most significant single advance in waste-water treatment possible.

So long as no simple solution to the sludge problem is found, treatment processes that produce little sludge, or sludges that are easy to handle, will gain favor. The biological processes are especially troublesome because the cellular material produced by the microorganisms strongly hold several times their weight in water. This is why physical-chemical systems, although not yet widely used, are so attractive. Ideally, chemicals that produce no precipitates or precipitates from which the original chemicals can easily be extracted (as in the lime process) would be used. This chemical treatment would be combined with steps (such as screening, filtering, and absorption) in which solids rather than sludges are collected.

The Battle Has Not Been Won

Although much progress has been made recently in waste-water treatment, many difficulties remain. The major one, of course, is getting the money to put the knowledge gained in the pilot plant studies into operational systems. The FWQA estimates that it will cost $10 billion to get domestic wastes up to recommended standards and $3.3 billion for industrial wastes.

On the scientific front, there is the necessity for understanding some of the fundamental processes of sewage treatment, such as phosphate precipitation and water retention by sludge. There is also the need for better survey and analytical work. For example, general characteristics like BOD and suspended solids are useful for plant management work and evaluation, but knowledge of exact chemical composition and particle size is needed for research.

Comprehensive surveys have been made of domestic sewage, but little is known of industrial wastes. The FWQA estimates that the volume of industrial waste water is about 2.6 times that of domestic. They also estimate that about half the volume of sewage treated in domestic facilities comes from industrial sources. This means that a volume of industrial sewage about three-fourths that treated in domestic facilities is unaccounted for. Disposal volumes for a number of specific industries have been estimated, but the overall industrial picture is not clear. The FWQA says: "The lack of reliable information on industrial water pollution control activities might be considered to be intolerable, if the nation had not become quite habituated to it. The guessing process has gone on for so long that it is considered quite normal; and every effort to initiate an industrial waste inventory has been frustrated without noticeable public comment" (*2*).

Another difficult but important survey that is required is to determine the composition of water that runs directly from land to natural waterways. In some cases—the Potomac River, for example—eroded soil is the major contaminant. Much waste from the agricultural industry also is direct runoff, and it has been estimated that perhaps half of the phosphates in natural water come from this source.

Finally, the problem of trace contaminants and health is not well studied. The recent series of discoveries of mercury contamination illustrate a process that has now been repeated several times. Routine water analyses are made only for major indicators of water pollution, so that measurable amounts of unusual substances can be present for long periods of time without being detected. Once a systematic search is made, some of the substances are found to be rather common. This happened with DDT, detergents, phosphates, and now it has been repeated with mercury. What other poisons have we not looked for?

The Waste Water Reclamation Committee of the American Water Works Association at their July meeting in Washington, D.C., cited the possible presence of the following substances as one reason for not utilizing reclaimed water if other sources were available: "chemical and biological toxins, trace elements, pesticides, carcinogens, antibiotics, hormones, viruses, and materials not yet studied."

Thus, although a broad-based research and development program in waste-water treatment is being pursued, much work remains—monies must be made available, fundamental research problems should be solved, and a major health catastrophe must be avoided by carefully monitoring our waters for small amounts of dangerous substances (*3*).—ROBERT W. HOLCOMB

References

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3. For a thorough summary of water treatment and a bibliography, see Subcommittee on Environmental Improvement, Committee on Chemistry and Public Affairs, *Cleaning Our Environment: The Chemical Basis for Action* (American Chemical Society, Washington, D.C., 1969), pp. 93–162.