Research in Progress

Acid Rain

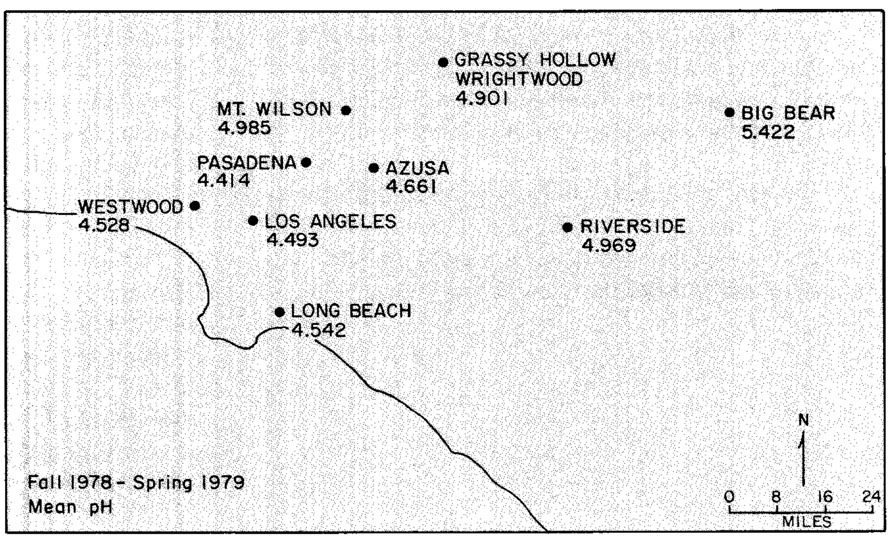
Pure as the driven snow? Despite this old saying, scientists are finding that precipitation over industrial areas is not so pure anymore but carries pollution back to the earth as acid.

This is also true of southern California, say James J. Morgan, professor of environmental engineering science, and Howard M. Liljestrand, a recent doctoral graduate working under Morgan. Under contract from the Air Resources Board, Morgan has undertaken a detailed definition of the chemical composition of rainfall in southern California, more specifically in the Los Angeles area, and its relation to that of the rest of western United States and the East.

Recent studies, with attendant alarming publicity, have shown a marked increase over the past few decades in the acidity of rain and snow in northern Europe and the northeastern United States, both highly industrialized areas. But the West, with its open spaces and less concentrated industry, has remained largely unresearched — until now.

Although there is little background historical data, acidity is probably a newcomer to the West. Using an indirect method to back-calculate probable figures for the pH of various western sites, Liljestrand found that the rain was actually alkaline as recently as the 1950s. Some sites had a pH as high as 7, while most were in the 6 range. (Although 7 is neutral in a closed system, pure water in equilibrium with the atmosphere has a pH of 5.65 due to dissolved carbonic acid; hence 5.65 is used as a reference point, and any atmospheric pH above it is considered alkaline.) This alkalinity is not surprising, since so much of the West's alkaline soil is blown into the air as dust.

Liljestrand's measurements of the Los Angeles area during the fall of 1978 through the spring of 1979 show an entirely different picture, however — a picture that is especially startling in light of the alkalinity of the recent past. Acidity ranged from a pH of 4.54 in Long Beach and 4.41 in Pasadena to 5.42 at Big Bear. There is a clear gradient from coast to mountains caused by the pollutant sources —



Even in alkaline southern California, rain can be acid — as shown by the pH measured at various sites in the Los Angeles area last year. The map also indicates a clear correlation between rain acidity and the sources of pollution.

automobiles and power plants — and the prevailing winds. Southern California is not downwind of any other major polluter, as are some unlucky places in the East, so the acidity in the rain here is all produced locally.

Liljestrand also conducted more detailed measurements and chemical analysis of precipitation in Pasadena over a four-year period, collecting in the entire study approximately 15,000 pieces of data. Measurement of rainwater composition over time showed, among other things, that the rate of rainfall caused extraordinary changes in pH. As rain intensity increases, acidity drops off.

Although a number of substances contribute to the problem, the essential ingredients of acid rain are the nitric and sulfuric acids resulting from the combustion of fossil fuels. Among Liljestrand's interesting findings is the fact that precipitation in the Los Angeles basin — compared with the East and Europe — has a higher ratio of nitrates, which come primarily from auto emissions (although from power plants as well), to sulfates, which are produced mainly by industrial sources.

In spite of the fact that what goes up must come down, Liljestrand found that most of the pollutants do not come back down in rain. Advection, or blowing away, rids the area of most of the nitrogen and sulfur oxides. The second most important mechanism for removal of acidity from the Los Angeles "airshed" is the settling of aerosol (smog) and gases back into the terrestrial ecosystem. Rain in this semi-arid climate actually accounts for comparatively little acid removal from the atmosphere. The study is giving the two scientists a feeling for the relative importance of the different mechanisms.

While raindrops serve to gather harmful gases, they also dilute them, and dry transport of gases and aerosol is potentially more damaging. For example, an aerosol with a pH of 2 can burn a hole in a leaf. Although the long-run effects can only be guessed at, pH is a master variable that controls a lot of things. Acidification may deplete trace metals, and lake populations are particularly sensitive to acid.

At the very least, rainwater has sustained a blow to its image. Far from being a carrier of pollution, it has been considered the purest water available as well as the cleanser of the atmosphere. It cannot be both.

Battery Power

Back in 1968 senior Wally E. Rippel drove the Caltech entry in the cross-country Great Electric Car Race to a half-hour victory over the MIT car (*E&S,* October 1968). Rippel drove his own 1958 Volkswagen bus converted to electric power with a lead-acid battery. MIT's losing entry in the race ran on nickel-cadmium batteries.

Rippel is back, now as a member of the technical staff of JPL, and is more than ever an advocate of electric cars and lead-acid batteries. He and his colleague at JPL, Dean B. Edwards, also a Caltech graduate (MS '73, PhD '77), claim that this traditional battery, with a little help from space-age materials, may prove to be the most efficient and economical source of electric car power over the next decade.

Although the lead-acid battery has been around for more than 100 years and probably has been developed as far as it can go for starting gasoline engines, applying new materials to the old concept offers considerable potential for improvement in application to electric cars.

The conventional lead-acid battery used in gasoline powered cars has lead grids holding electrochemically active lead materials in place. Although the grids themselves do not store energy, they add considerable weight and restrict the battery's power performance.

An alternative approach, the "bipolar construction," does away with the grids and uses thin conductive sheets (biplates) to conduct electricity from one cell to the next. Since this construction has the potential for weight reduction and higher power, numerous attempts have been made to develop such bipolar batteries. However, in the case of bipolar lead-acid batteries, virtually all such efforts have failed because of materials problems with the biplate.

Thanks to graphite fibers, a new lightweight material, Edwards and Rippel may have found a solution to the biplate problem. Their approach, using graphite fibers molded into thin sheets of polyethylene, allows a reduction in dead weight as well as increased plate surface area. This increased surface area leads in turn to improved electrochemical performance of the energy-storing materials.

One of the new battery's key features is its performance. With four times more power per pound, it will far outperform conventional lead-acid batteries in acceleration, in climbing steep hills, and in maximum speed. According to the two engineers' calculations, their battery will enable an electric car to go from a full stop to 60 miles per hour in 12 seconds, even when the battery is 80 percent discharged.

The bipolar lead-acid battery is expected to last an estimated 50,000 to 80,000 miles, which is substantially longer than other types of batteries currently being developed. Its projected range capability of 150 miles before recharging makes a practical electric vehicle a real possibility within the next few years.

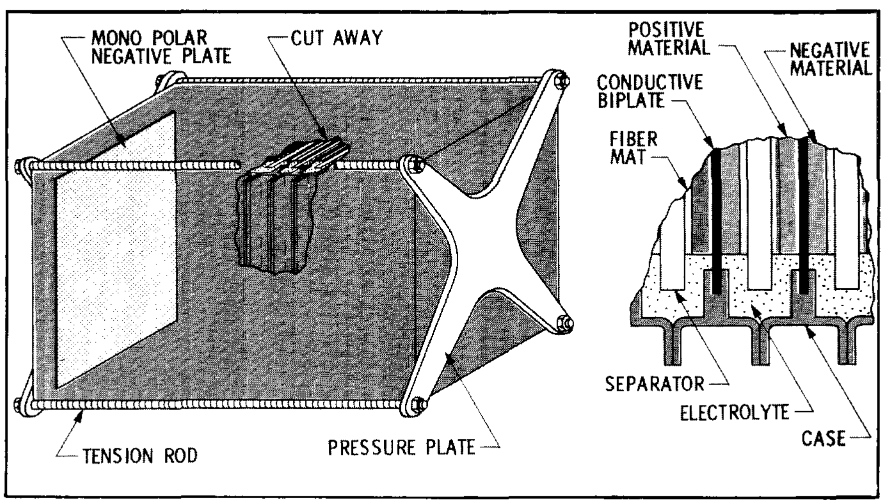
Another advantage of the new bipolar lead-acid battery is that it produces less heat than its conventional counterpart. Overheating was a problem that plagued both the MIT and Caltech cars in the cross-country race 11 years ago, a problem that was then solved by packing the battery areas full of ice. Alternate batteries, such as General Motors' new zinc-nickel oxide battery, are even more sensitive to high temperatures than lead-acid ones and could present difficulties in desert areas.

Another advantage the bipolar lead-acid battery has over nickel-type batteries is cost. Nickel is expensive and must be imported, while lead is cheap and available in adequate domestic supply. Rippel estimates that a bipolar-powered car would have an energy expense of about one cent per mile.

The first phase of basic research on the battery has been completed, and Edwards and Rippel's immediate goal is to demonstrate acceptable performance of the polyethylene-graphite fiber biplate — the key element in their invention. Portions of this work will be carried out jointly with Caltech Associate Professor of Engineering Design David F. Welch and his students. They will be involved with some of the mechanical aspects, such as fabrication of the molds for the experimental parts.

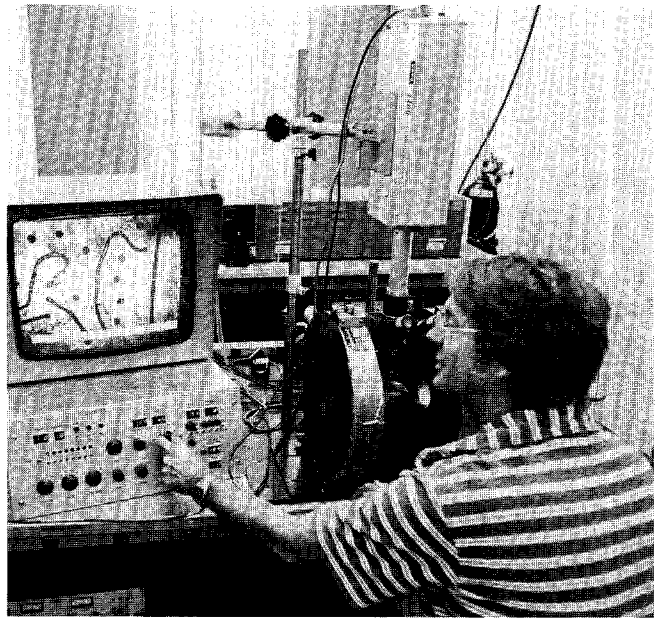
In case you're wondering, Rippel still drives an electric car and has logged nearly 50,000 miles in a Datsun converted to electric power — with a lead-acid battery, of course.

The men behind the development of the bipolar lead-acid battery — Wally Rippel and Dean Edwards, with David Welch. Edwards holds a sample of the graphite fiber material.



Thin, light biplates of polyethylene and graphite fibers connecting the bipolar lead-acid battery cells allow a greater number of cells to be stacked together for more power per pound.

Magnetic Bubbles



Floyd Humphrey adjusts video micrometer to measure one of a group of magnetic bubbles photographed through a microscope by a laser (at the rear to the right of the screen). The snake-like lines on the screen are "stripe domains" — another shape of bubble.

Over in Steele Laboratory they're watching bubbles — not soap or champagne, but magnetic bubbles, about 1-10,000th of an inch in diameter. These tiny magnetized areas are used in computer information storage, where they have the particular advantage of not "losing their memories" if power is turned off.

Development of bubble technology was begun at Bell Laboratories in 1966; bubble memories have been in use for the past five years, but a better understanding of some of their fundamental functions should greatly improve the technology. That's why Floyd B. Humphrey, professor of electrical engineering and applied physics, is watching bubbles. He is particularly interested in the physics of how they move — the dynamics of the bubble walls.

To begin creating bubbles, a thin magnetic film is grown on top of a non-magnetic single crystal. When subjected to a uniform magnetic field, the film will be magnetized in a perpendicular (upward) direction. If a particular spot is then magnetized in a downward direction, a bubble of finite size appears over that spot. Millions of them will fit on a dime-sized crystal. These bubbles are extremely stable and, since the uniform field is supplied by a permanent magnet, independent of power.

How do they move? Since a bubble will move to the spot where the magnetic field is lowest, local changes can be made in the uniform field by a pattern of small metal "magnets" put on the crystal's surface. By rotating a field that is parallel to the plane of the film, the magnetic pattern can be affected so that the point of least magnetic field at the bubble changes continually; the bubbles can be made to progress regularly from place to place through the pattern. Information is stored by the presence or absence of a bubble at a particular spot — bubble or no bubble, one or zero (in binary terms), on or off.

In order to learn what happens to the structure of these fast-moving magnetic areas as they go from one spot to another, Humphrey photographs them through a microscope with a flash 10 nanoseconds (10×10^{-9} seconds) in duration; the usual camera flash lasts about three-thousandths of a second. Humphrey's flash is a laser-driven laser, continuously taking individual pictures, which are translated onto a television screen through a silicon intensified-target videcon. This method produces what appears to be a continuous moving picture of the bubbles and simultaneously records the images as well as data on what was done to produce and manipulate the bubbles. Later these images can be studied, one picture at a time, and the bubbles observed and measured as they move, expand, contract, and deform.

Ultimately Humphrey and his students want to know how the bubbles work in a computer memory. They study bubbles in memory devices, particularly in situations where they do not act as expected. Then the researchers try to recreate the same situation with "free" bubbles (not in a device and therefore more understandable) to figure out what is happening to them and why they act as they do.

In the course of his work Humphrey has added considerably to the understanding of bubble walls and how they move. He has discovered many different kinds of wall structures and invented a theory to account for the bubbles' apparent momentum. And as long as there is more to be learned about this new technology, Humphrey's lab intends to keep on bubbling.