Cleaning up Coal: A New Entry in the Energy Sweepstakes

Environmental restrictions on burning coal to generate electricity are beginning to pinch. As of last month, nearly every coal-fired power plant in the eastern half of the United States is technically in violation of Environmental Protection Agency standards by virtue of its sulfur dioxide emissions, although delayed compliance schedules and massive variances have kept plants in operation. The electric utility companies face restricted and often unpalatable options, including transporting low-sulfur western coal great distances or constructing stack gas scrubbers to remove sulfur dioxide which are expensive and of arguable reliability. Thus the announcement last week by Battelle Memorial Institute of Columbus, Ohio, of a newly developed process for removing sulfur from coal prior to combustion is timely indeed.

Battelle's entry, developed with $2 million of its own funds, consists of a hydrothermal process not unlike those used to extract ores in the mineral industries. In essence, sulfur is leached from coal with a strongly alkaline solution at moderate temperature and pressure. The process is not only simple and apparently applicable to many high-sulfur coals, it also promises to be relatively inexpensive. Battelle estimates a cost of $10 to $15 a ton in a full-size plant, which if realized would make the process cheaper than many comparable methods of cleaning up coal. The process is environmentally attractive as well, in that it does not produce large volumes of waste and the reactant chemicals are recycled and reused. The coal that emerges is low in sulfur—less than 1 percent residual sulfur in experiments with samples from six different eastern and midwestern coal seams—and impregnated with alkali that captures additional sulfur during combustion. Battelle scientists believe that their process will eventually obviate the need for scrubbers or other devices on power plants that burn hydrothermally treated coal.

The process is thus likely to stimulate considerable interest among utility companies, although it is not yet commercially proved and many power plants face immediate compliance measures. Battelle has operated the process continuously for several hundred hours in a laboratory-scale pilot plant capable of processing 0.25 ton of coal per day. The institute has approached a group of Ohio utilities for $30 million to build a larger experimental facility capable of treating 50 tons per day, on the basis of which it hopes to license construction of commercial plants, possibly within 3 to 4 years.

The group of potential backers includes American Electric Power, Inc., which last year waged a colorful public campaign against scrubbers. The Battelle process may in fact become a new arguing point for those who believe that the Environmental Protection Agency, in promoting scrubbers, is forcing widespread adoption of an inefficient and obsolete technology. Some 21 scrubbers are now operating in the United States, nearly 100 more are either under construction or in some stage of planning, and many East Coast power plants that now burn oil are under pressure from the Federal Energy Administration to convert to coal. Thus the debate over scrubbers is likely to intensify, because neither the Battelle process nor most other coal cleanup schemes are expected to be available before the 1980's. Battelle president Sherwood Fawcett estimates that the first commercial plants using the hydrothermal process would not begin operation until 1982.

For Battelle, the hydrothermal process appears to be an early payoff from its energy R & D program. Announced in 1973 as a $25-million, 5-year program to be supported entirely with internal funds, the program is devoted to coal, of which there are great reserves in Ohio, most of it high in sulfur content. Battelle has been under fire from Ohio authorities in recent years concerning the interpretation of the will under which the institute is chartered and particularly concerning the disposition of its earnings (*Science*, 13 December 1974, p. 1007). The energy program was motivated not only to make a contribution to the U.S. energy posture but also in part to counter this criticism. Ironically, a court settlement of the dispute earlier this year has forced Battelle to scale down its energy program substantially (to approximately $8 million). The decision to seek local backers for further development of the hydrothermal process also appears to reflect the institute's new concern with its political profile in Ohio.

Just how significant a contribution to solving Ohio's and the nation's energy problems the hydrothermal process represents will become clearer as further testing goes on, but the simplicity of the process argues well for its prospects (Fig. 1). Coal and some makeup water are the primary ingredients fed into the process; low-sulfur coal, elemental sulfur, and a small residue of metallic compounds and coal chemicals are the main products. All of the products are potentially salable.

Raw coal is ground up and mixed with a leaching fluid to form a slurry. The leachant used is an aqueous solution of sodium hydroxide and calcium hydroxide, with up to 10 percent NaOH and about 2 percent $Ca(OH)_2$, the exact proportions dependent on the sulfur content and other properties of the coal being treated. The slurry is pumped into pressure vessels, where it is held for up to 30 minutes at pressures be-

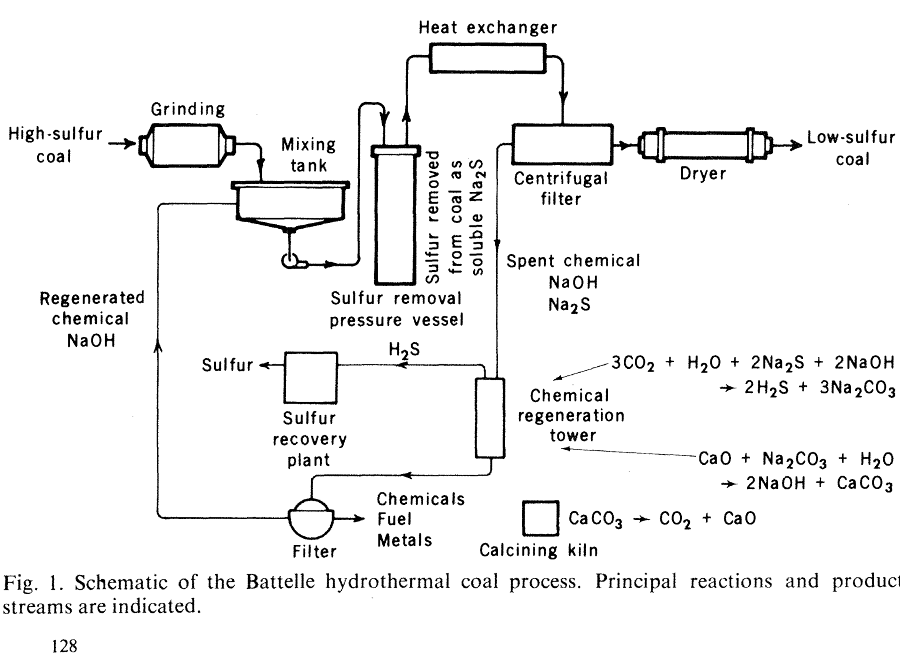


Fig. 1. Schematic of the Battelle hydrothermal coal process. Principal reactions and product streams are indicated.

tween 350 and 2500 psi (1 psi = 6.89×10^4 dyne/cm^2) and temperatures between 225° and 350°C (again depending on the particular coal). The chemicals are then filtered off, regenerated and recycled, and the coal, after washing and drying, is ready for burning.

According to Battelle, this treatment is sufficient to remove nearly all inorganic sulfur and about half of the more tightly held organic sulfur. In experiments with six different types of bituminous coal, the extraction efficiency for organic sulfur varied from 24 to 72 percent. The treatment also removes part of the ash, some of the toxic metals present in coal (including lithium, beryllium, vanadium, arsenic, lead, and thorium), and about 5 percent of the coal itself. An additional treatment step, rinsing the coal with a dilute acid, would make it possible to extract most of the re-

Quasars Flare Sharply: Explaining the Energy Gets Harder

During the last two decades, astronomers have realized that extraordinarily powerful and violent events are commonplace occurrences in the universe. The enormous energies of quasars, large radio sources, and other peculiar objects are continuing puzzlements. Recent research at Harvard University has magnified the problem of the quasars by showing that one of the brighter ones underwent a previously unsuspected flare in 1937, and for a period of several months was the most luminous object known in the universe.

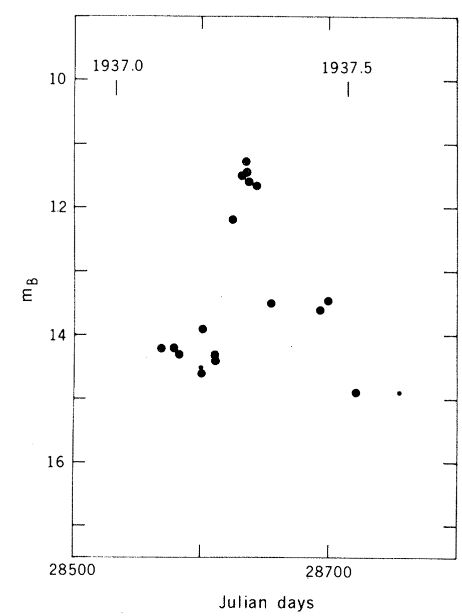
In April of 1937, quasar 3C279 intensified very quickly from its normal optical brightness of 15th or 16th magnitude until it reached a maximum brightness of magnitude + 11.3. The quasar is thought to be more than 5 billion light-years away, assuming that its red shift (0.536) is equally as good a measure of distance as are the red shifts of normal galaxies. At such a distance, the absolute magnitude of 3C279 at the peak of its flare must have been − 31.4. (The magnitude scale of optical brightness is logarithmic, with negative values brighter than positive ones, and five magnitudes equivalent to a factor of 100.) At such a high optical luminosity, the quasar would have been emitting 10^{48} erg/sec.

For comparison with other objects in the universe, the absolute visual magnitude of the sun is + 4.7, that of the entire Milky Way is − 20; the absolute magnitude of a giant elliptical galaxy is typically −22, and that of a bright quasar −26. The flare that occurred in 1937, shown in the figure below, was a phenomenon equivalent in effect to turning on thousands of giant galaxies in a matter of months and then turning them off again. But because the event happened so quickly, the short distance that light could have traveled in that time suggests that it occurred in a region far smaller than a single giant galaxy. "The flare was absolutely huge," according to Harry van der Laan at Leiden Observatory, Netherlands, and constitutes a whole new limit for the energy problem in astronomy.

The photographic plates that contained the record of the depression-era flare of 3C279 were recorded as part of a systematic observing program pursued by the Harvard College Observatory for almost 70 years, from 1885 to 1954, and recently renewed. From the observatory site in Cambridge, Massachusetts, and from the Agassiz station about 40 miles away, Harvard astronomers conducted a regular patrol of the Northern Hemisphere. Regular coverage of the Southern Hemisphere was carried out at the Harvard southern station, which was located in Arequipa, Peru, until 1924 and then moved to Bloemfontein, South Africa. About 500,000 plates were made during the time the sky patrol was active. Every portion of the sky was typically photographed with wide-angle cameras several times a year.

The plates have been carefully stored on three floors of the old observatory building, which now adjoins the building of the Smithsonian Astrophysical Observatory. Two years ago, with the encouragement of George Field, who sits as director of both institutions, Harvard astronomers began looking into the plate collection for data that would be relevant to some of the newer scientific frontiers—particularly high-energy astrophysics. William Liller and associates at Harvard found evidence for a regular optical period in the brightest x-ray source in the sky, Sco X-1, and also began a survey of the variability of the optical emissions of the brighter quasars. William Liller, Martha Liller, and Lola Eachus found evidence for flares not only in 3C279, which exhibits the most pronounced flare discovered so far, but also in quasar PKS 1510-089, and in the quasar-like object MA 0829 + 047. There is also some evidence from the Harvard plates that quasar 3C279 flares regularly every 7 years, since brightness peaks were recorded in 1944 and 1951.

The power produced by quasar 3C279 peaked at a value greater than that known for any other object. Over one period of 13 days in 1937, the quasar emitted an average of 10^{41} watts, assuming it is at the cosmological distance given by its red shift. This is an enormous power, comparable to that discussed in trying to explain the double radio sources (*Science*, 27 June 1975). The radio sources continually emit 10^{37} watts. But Geoffrey Burbidge, at the University of California, San Diego, suggests that it may be just as much of a problem to explain how radio sources can emit 10^{37} watts for millions of years as to explain how quasars can emit 10^{41} watts for a few days or months.



As one of the school of astronomers who question whether the red shifts of quasars are indicators of their cosmological distances, Burbidge also questions whether 3C279 really became as bright as magnitude − 31.4. But he thinks that the discovery is nonetheless significant. Either 3C279 is much closer, according to Burbidge, or else "you cannot appeal to the evolutionary processes of normal stars" to explain it.—WILLIAM D. METZ maining ash. Since toxic metals and ash particulates in the exhaust gases from power plants pose a health problem that some scientists believe is more worrisome than sulfur dioxide (although the matter is controversial), their removal is a significant side benefit of the hydrothermal process.

Regeneration of the alkaline leaching solution also includes recovery of sulfur and, potentially, of the metals extracted from the coal. The spent leachant is treated with carbon dioxide and lime (calcium oxide), both of which are themselves recovered. The carbon dioxide serves to lower the alkalinity, converting sodium hydroxide to sodium carbonate and releasing sulfur in the form of hydrogen sulfide gas; in a commercial plant the gas would be captured and converted to elemental sulfur, which is readily stored or sold. Lime is then added to the solution, regenerating sodium hydroxide and precipitating calcium carbonate, small amounts of dissolved coal, and metallic compounds. Although the details have not yet been worked out, Edgel Stambaugh of Battelle, the principal inventor of the process, believes that the trace metals can be recovered and purified by selective leaching; the dissolved coal can be burned to provide heat for operating the process or, since it contains a high proportion of aromatic compounds, may possibly be converted to marketable compounds such as terephthalic acid, which is used to make synthetic fibers. In a final step, the calcium carbonate precipitate is heated to regenerate lime and carbon dioxide, thus closing the cycle.

Inorganic sulfur, present in coal as iron sulfide, is relatively easy to remove. The primary claim of the Battelle process is thus that it can remove a portion of the organic sulfur present as part of the coal. Organic sulfur is also removed by several other prospective methods of producing a coal-based boiler fuel for use in power plants. These competitors to the hydrothermal process include liquefaction, gasification (to make a low-Btu power gas, not a methane-rich pipeline gas), and solvent refining (in which organic solvents are used to remove sulfur and ash). These processes are more complicated than the Battelle method, although they are also further developed, and Battelle scientists believe they will prove substantially more expensive.

Among other advantages, the hydrothermal process produces a solid fuel which, in contrast to gaseous boiler fuels, is easy to store. Stambaugh believes that the purified coal will also make an ideal starting material for producing pipeline-quality gas or liquid fuels, because it no longer cakes together and will undergo gasification at lower temperatures and pressures than raw coal. If hydrothermal processing plants were to be built in the coal fields, the coal slurry that emerges from the desulfurization step could be pumped directly into pipelines and transported to power plants in that fashion.

Unexpected difficulties may arise in scaling up from the present 0.25-ton-per-day pilot plant to the 10,000-ton-per-day capacity required to feed a 1000-megawatt power station. But if the process performs as Battelle expects, and if costs indeed turn out as low as a projected $110 million for a full-sized commercial facility, reserves of eastern and midwestern coal, which cannot now be burned without installation of scrubbers, would become available. Because coal is not only the largest U.S. energy resource but must also become increasingly the main energy source for electric utilities and other industries for at least the next 20 years, the Battelle process would seem to be a significant addition to the relatively limited repertoire of coal technologies.—ALLEN L. HAMMOND

Precautions for Viking

For the past year planetary scientists have been discussing, and initially dismissing, a Soviet report that unexpectedly large amounts of argon may be present in the martian atmosphere. But reevaluation of the Soviet data and evidence from a new spectroscopic study have resulted in the possibility being taken more seriously. Argon could cause failure in a key instrument on the soon-to-be-launched Viking spacecraft; as a precautionary measure, National Aeronautics and Space Administration (NASA) scientists have decided to rearrange the order in which Viking experiments on the martian surface will be conducted. An atmospheric experiment, in which argon could come in contact with the spacecraft's primary mass spectrometer, is to be postponed until after biological experiments, which are also programmed for the instrument, are completed.

The Soviet report comes from the Mars 6 spacecraft that landed on the planet in March 1974. The spacecraft ceased operating (apparently it crashed) when it reached the surface, but signals were received during its descent through the atmosphere from a pump attached to a mass spectrometer that had been turned on to warm up. The current in the pump rose sporadically, indicating that it was having trouble. Because the pump, like a comparable piece of equipment on Viking, is powered by chemical reactions between titanium and the gas being pumped, an inert gas like argon would inhibit its operation. On the assumption that this was indeed the cause of the pump's erratic behavior, Soviet scientists calculate an argon content of 25 to 45 percent for the martian atmosphere—high enough to make the Viking mass spectrometer inoperable too. The calculation is subject to considerable uncertainty, however, and was skeptically received by many U.S. scientists.

Now they are not so sure. Several factors seem to have contributed to the change in attitude. The Soviet scientists have been very open about discussing the argon data and instrumental techniques with their American counterparts. One of the pioneering inventors of flight mass spectrometers, A. O. Nier of the University of Minnesota, looked into the Soviet claim in some detail and pronounced it not impossible that argon was responsible for the failing pump—a judgment that seems to have carried considerable weight with other scientists. And recently, Lewis Kaplan of the University of Chicago estimated argon on Mars on the basis of the absorption spectra observed by Pierre Connes of the Centre National de la Recherche Scientifique, Orsay, France. From these Kaplan calculates a discrepancy between the total surface pressure and the partial pressure due to carbon dioxide that could be attributable to argon. The most probable value, he finds, is 25 percent of the atmosphere, plus or minus at least 25 percent; but because of the many possible sources of error in the procedure, however, he credits his results with very little reliability. About all one can conclude, he believes, is that large amounts of argon cannot be excluded.

Not wanting to risk failure of the biological experiments that are the main raison d'être of Viking, NASA officials have sensibly planned to do them prior to atmospheric tests when the first of two Viking landers touch down. Nor are atmospheric scientists unhappy at the turn of events. If argon is present, that may prove to be far more interesting than the data originally anticipated from the atmospheric experiments.—A.L.H.