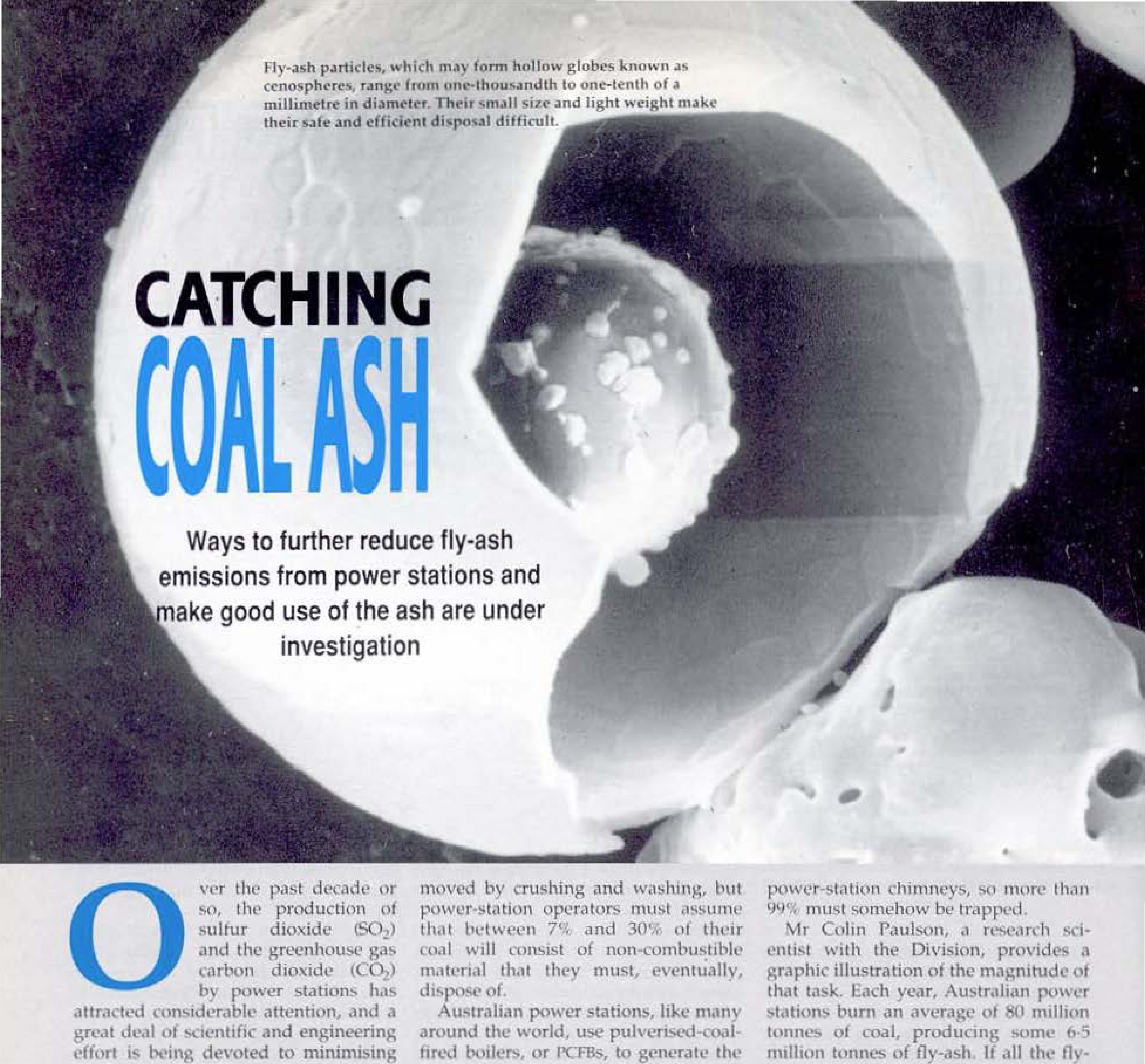
CATCHING COAL ASH

Ways to further reduce fly-ash emissions from power stations and make good use of the ash are under investigation



Fly-ash particles, which may form hollow globes known as cenospheres, range from one-thousandth to one-tenth of a millimetre in diameter. Their small size and light weight make their safe and efficient disposal difficult.

Over the past decade or so, the production of sulfur dioxide (SO_2) and the greenhouse gas carbon dioxide (CO_2) by power stations has attracted considerable attention, and a great deal of scientific and engineering effort is being devoted to minimising emissions.

The CSIRO Division of Coal and Energy Technology is active in this area, developing 'cleaner' coal and contributing to the design of power stations that produce less atmospheric pollution.

But that is only part of the equation; just as important is the need to control the solid waste that power stations generate.

The overwhelming majority of power stations throughout the world are coal-fired, and that means they produce fly-ash, so called because it is so fine — the consistency of talcum powder — that it floats easily in air. Fly-ash, in fact, reveals that coal doesn't consist only of carbon. In its natural state, coal occurs in bands a few millimetres to several metres in thickness, interspersed with various forms of mineral matter. Some of this can be removed by crushing and washing, but power-station operators must assume that between 7% and 30% of their coal will consist of non-combustible material that they must, eventually, dispose of.

Australian power stations, like many around the world, use pulverised-coal-fired boilers, or PCFBs, to generate the steam that drives the turbines that generate electricity. Pulverised coal blown into the PCFBs burns at temperatures of up to 1750°C.

Finely ground coal particles (on average, 0·05 mm across) in a PCFB move randomly under the effects of the fans forcing them into the boiler, and of internal turbulence. Temperatures are high enough to soften or melt most of the mineral matter present: by the time the coal has been consumed, the fly-ash that remains consists of a mixture of particles, from angular shapes to perfect spheres ranging from 0·001 mm to 0·1 mm in diameter, with an average size of one-hundredth of a millimetre.

Fly-ash leaves the boilers at a concentration of up to 20 grams per cubic metre; but Australian regulations permit a maximum of only about 250 mg of fly-ash per cu. m to escape from power-station chimneys, so more than 99% must somehow be trapped.

Mr Colin Paulson, a research scientist with the Division, provides a graphic illustration of the magnitude of that task. Each year, Australian power stations burn an average of 80 million tonnes of coal, producing some 6·5 million tonnes of fly-ash. If all the fly-ash produced in New South Wales alone could somehow be dumped over a single square kilometre centred on the Sydney Harbour Bridge, it would reach the Bridge's roadway in 15 years, bury the shells of the Sydney Opera House in 16 years, cover the top of the Bridge arch in 34 years... and reach as high as the tip of Sydney Tower in 66 years!

Reducing fly-ash emissions to less than 1% represents a degree of efficiency well beyond the capabilities of most industrial processes, but it is achieved through a method that actually dates from the Age of Enlightenment. The principle of electrostatic precipitation was first described in the 18th century, by the 'scientific gentlemen' of Britain's Royal Society, originally as a curiosity of physics but — following the industrial revolution those same scientific gentlemen helped to establish — as a standard method of trapping the particles.

Electrostatic precipitation as a commercial process dates from 1907 and, although major advances in precipitation technology have occurred since then, it is only in the past 20 years that very high efficiencies have been required. In a modern system, gas containing fly-ash is pumped from the PCFBs to an electrostatic precipitator, which contains metal plates up to 15 m high, each up to 5 m wide, suspended 20–40 cm from each other. Wires carrying tens of thousands of volts hang between the plates; the wires are not earthed, so they create negative charges within the precipitator, which in turn charge the fly-ash particles. These are then attracted, and adhere, to the metal plates, which are earthed. At regular intervals a simple hammer arrangement hits the plates, knocking off the accumulated fly-ash for disposal.

An alternative method employs thousands of fabric filter bags (gigantic versions of the familiar domestic vacuum-cleaner bags). At Eraring power station on the New South Wales central coast, each PCFB feeds a chamber containing 48 000 such filter bags 16·5 cm in diameter and 5·5 m long. Gas containing fly-ash particles is fed under pressure from the boilers into holes (to which filter bags are attached) in the top of each chamber; the bags trap the fly-ash particles but allow gases to escape.

However, filter bags cannot be repaired and represent a continuing expenditure for power-station operators.

Mindful of the strict emission levels in force in Europe and the United States of America, Division of Coal and Energy Technology researchers are working to improve the efficiency of electrostatic precipitators still further.

As Mr Paulson explains, emission levels are being reduced to 50 mg per cu. m in some countries, and it is likely that present Australian levels of 250 mg per cu. m will be reduced to 100 in the foreseeable future. This may push the required efficiency of fly-ash collection as high as 99·9%. Precipitators must also be absolutely reliable, since a power station takes several hours to shut down completely. Large amounts of fly-ash could escape into the atmosphere before corrective action took effect.

That would represent more than a serious clean-up problem; a sudden efflux of fly-ash could present long-term pollution problems downstream from power stations, most of which are located near rivers or lakes because of their need for cooling water.

Australian Overseas Information Service

As the managers of coal-fired power-stations know only too well, coal does not consist simply of carbon: up to 30% of it is composed of clay, metals and other substances that form fly-ash after coal is burnt.

To minimise the possibility of such impacts and to maximise the efficiency of fly-ash precipitators, the Division has been working since the 1960s, originally with the Electricity Commission of New South Wales, to study the behaviour of precipitators.

Program leader Mr Paulson began by building his own miniature power station (albeit without a turbine, so it does not generate electricity) at the Division's North Ryde headquarters, to study the behaviour of precipitates and to build up a profile of different types of coal with a view to assessing their requirements for fly-ash collection.

He has found, for example, that the amount of sulfur in coal plays an important role. Some American and British coals, with a 3-4% sulfur content, produce more sulfur oxides including SO_3; this assists electrostatic precipitation, making fly-ash easier to collect, but of course SO_2 also has the major drawback of being a source of acid rain if produced in large amounts. Australian coals contain an average of 0·5% sulfur.

The Division has conducted experiments over the past 20 years to establish a coal and fly-ash data-base that is consulted by power-station operators and designers around the world (Mr Paulson recently tested Indian coal, in Australia, on behalf of a British company) and that is regarded as an unequalled source of expert, objective information.

Over most of those two decades of research, Mr Paulson and his colleague Mr John Vale required 5 tonnes of raw material to build up a profile of any nominated variety of coal. (A 'real' power station, on the other hand, would need 50 000 tonnes to derive the same amount of information on performance, pollution and fly-ash characteristics.)

Since 1986, however, they have been able to obtain most of the information they need from no more than 300 g of coal. This is enough to allow them to carry out mineral matter analyses, the results of which they feed into a mathematical model to estimate the size of precipitator required to collect fly-ash from that coal.

In work aimed at improving precipitator design, Mr Vale is taking advantage of video technology to see what happens inside a precipitator. This would hardly be possible in a working power station using conventional technology, since an atmosphere filled with hot, whirling fly-ash and 10 000 volts of electricity makes a more than merely hazardous environment. Instead, Mr Vale employs what he calls 'Ashcam', a finger-sized video camera of the type first used to provide television audiences with a driver's-eye view of motor racing.

'Ashcam' now allows him to look at various elements of the precipitator — to learn for the first time how fly-ash builds up on the suspended plates, how the flow of ash-laden gas affects the speed and efficiency with which ash adheres and how changes to precipitator design and operating procedures could affect the precipitator's ability to trap fly-ash.

Mr Vale is also developing new diagnostic tools that will provide more efficient monitoring of fly-ash emissions, thus helping scientists assess the performance of different precipitator designs and helping power-station operators abide by pollution-control regulations.

Non-carbon impurities in the original coal are concentrated by a factor of about five in the fly-ash, since 80% of the original mass of coal has disappeared as CO_2 and water. Mr Les Dale has analysed more than 70 types of steam coal used in power generation to assess the quantities of trace elements, such as selenium, arsenic, fluoride and lead, that they contain, and also to monitor what happens to those elements as they pass through a power station.

The question of whether those impurities could leach out of fly-ash disposal areas and adversely affect the local environment needs to be answered (leaching could also restrict the use of fly-ash in concrete and other products). Dr David Jones has examined the leachability of the substances present in fly-ash from each of seven power stations in New South Wales, by mixing a sample with water and measuring the concentrations of a large number of metals. The results show that fly-ash would not be classified as a hazardous waste material according to criteria developed by the United States Environmental Protection Agency (USEPA).

Dr Jones and his team also conducted tests in the field to see what was happening in the ash-disposal systems at three power stations. They were particularly concerned with measuring the concentrations of metals that could be bio-accumulated in individual organisms, or bio-magnified through the food chain; mercury, selenium, cadmium and lead are the elements of greatest concern in this context. The researchers collected samples of water and sediments at several locations downstream from the power stations and at reference sites to 'fingerprint' the source of the metals, and to study how much ended up in stream sediments, plants and animals. Sampling was repeated a number of times over a 3-year period to determine whether any noticeable changes were occurring.

Results from the Liddell, Wallerawang and the now-closed Tallawarra power stations in New South Wales showed that ash-disposal systems did not contribute to concentrations of lead, mercury or cadmium in either water or sediments. The levels of copper in the water were only slightly higher (at 3·5 parts per billion) than the upstream, or background, level of 2 p.p.b. (To put this into context, the State's drinking-water quality limit for copper is 1000 p.p.b., and the most stringent value for the protection of aquatic life advocated by the USEPA is 12 p.p.b.)

Dr Jones's work represents a significant contribution to understanding how power stations interact with their nearby environment, and has influenced the design of monitoring procedures and improved processes for management of discharges into ponds and rivers.

About 10% of fly-ash is currently 'recycled', mainly in the building and construction industries — for example, in high-strength, low-heat concrete for dam construction, salt-resistant concrete for artificial reefs, grouting, ceramic products, insulating wallboard, road base and asphalt filler.

The CSIRO Division of Building, Construction and Engineering has been involved in fly-ash utilisation in these areas since the mid 1970s. In the last few years, Mr Peter Mullins at the Division of Coal and Energy Technology has been conducting research focused on improving our knowledge of the chemical, physical, mechanical and thermal properties of various kinds of fly-ash in order to develop new uses and new markets for a hitherto largely ignored product. More recently, he has been looking at expanding the use of cenospheres — lightweight spheres of glassy fly-ash 10–200 microns in diameter — as a high-strength, low-density filler for engineering and architectural applications.

In industrial applications, cenospheres, although they have been regarded as a problem by power-station managers because they are so light that they tend to float on the surface of ash-disposal ponds, for all the world like windblown foam, may offer significant cost savings over other filler materials while providing improved strength and bonding. They could also be useful as fillers in the metals industry; since they are stable at high temperatures, they have the potential to add further lightness and strength to moulded parts of, for example, aluminium.

Some fly-ash contains useful amounts of magnetite — widely used in the mining and engineering industries — or of valuable metals such as titanium, and Mr Mullins is looking at improving techniques for recovering these.

Carson Creagh

More about the topic

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Coals in future iron and steel making. T. G. Callcott and R. Callcott. *Coal Journal*, 1990, **27**, 17–23.

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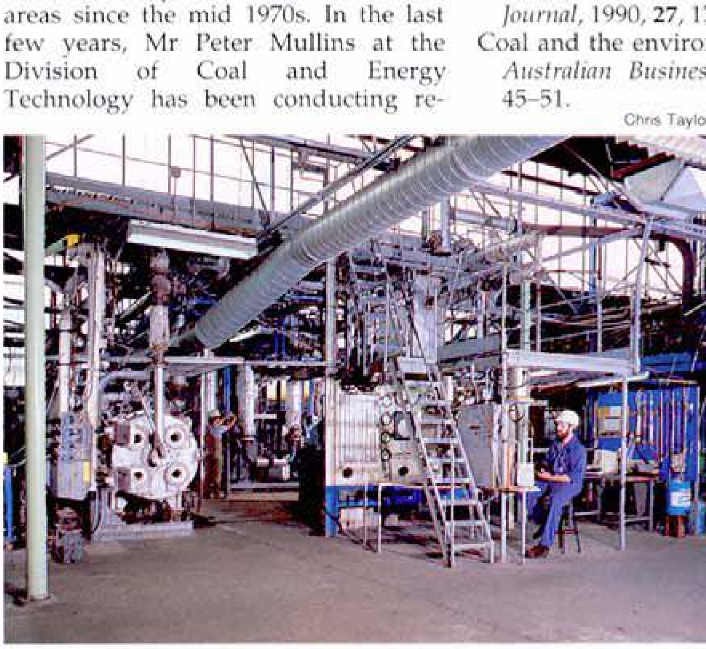
Chris Taylor



At the Division of Coal and Energy Technology, North Ryde laboratories, a miniature pulverised-coal-fired boiler is helping researchers improve the performance of power stations.